

# HID car headlights and road safety

C.C. Schoon & dr D.A. Schreuder



# HID car headlights and road safety

*A state-of-the-art report on high-pressure gas-discharge lamps with an examination of the application of UV radiation and polarised light*

R-93-70  
C.C. Schoon & dr D.A. Schreuder  
Leidschendam, 1993  
SWOV Institute for Road Safety Research, The Netherlands

SWOV Institute for Road Safety Research  
P.O. Box 170  
2260 AD Leidschendam  
The Netherlands  
Telephone 31703209323  
Telefax 31703201261

## Summary

This report first offers an overview of the processes of observation which play a role in vehicle lighting. To see and be seen are important considerations in this regard. The function and types of application of the dipped beam are dealt with on the basis of SWOV state-of-the-art report 'Lighting and marking of motor vehicles' (Schreuder & Lindeijer, 1987). Subsequently, the technical lighting aspects of HID lamps which have an influence on road safety are further investigated, supplemented by knowledge gained from recent research.

Due to the high light output of HID lamps and the presence of UV radiation, two possible areas of application are described: polarised light and the use of fluorescent material to enhance the visibility of objects. The health hazard presented by UV radiation is not ignored, however.

The distribution of light from the dipped light beam as stipulated by ECE regulation R20 is dealt with extensively in order to enable assessment of the proposed distribution of light from HID lamps.

The results of study into HID lamps in the United States as part of CIE and European research through EUREKA ('VEDILIS') are given. Many European manufacturers and research institutes are involved in VEDILIS (Vehicle Discharge Lighting System).

The discussion considers in detail the compromise that must be reached with dipped headlights: to provide the best possible illumination on the one hand and to prevent dazzle on the other.

It is concluded that the proposed distribution of light from the dipped light beam of HID lamps is higher than current ECE standards for virtually all points of measurement. These values need to be reduced on account of the negative aspects regarding the possibilities of perception of the other party (oncoming traffic and intersecting traffic) and the anticipated increasing speeds of motorists. In addition, solutions should be sought with regard to headlights which are dirty or aligned incorrectly. If these conditions cannot be met, the use of HID headlights for passenger cars should be discouraged from the point of view of road safety.

The report also concludes that the distribution of the light beam should pay greater attention to the position of vulnerable road users.

Reassessment of the function of motor vehicle lighting is considered desirable in response to road and traffic conditions which have changed in the last few years.



# Contents

## *Foreword*

1. *Introduction*
  - 1.1. The observation process
  - 1.2. Illumination
  - 1.3. Indication
  - 1.4. Single quantities of light
  
2. *Function and application of dipped headlights*
  - 2.1. Engineering
  - 2.2. Distribution of light from the dipped light beam
  - 2.3. Dipped headlights in traffic
  
3. *HID lamps*
  - 3.1. Engineering
  - 3.2. International research
  - 3.3. Distribution of light
  - 3.4. Aspects relating to dazzle from HID lamps
  - 3.5. Other aspects
  
4. *Special application of HID lamps*
  - 4.1. Polarised light
  - 4.2. UV radiation
  
5. *The effect of UV radiation on health*
  
6. *Discussion*
  
7. *Conclusions*

## *Literature*

## Foreword

In Europe and the United States there is a great deal of current interest in a new development in the field of motor vehicle lighting, the so-called high-intensity-discharge (HID) car headlight. This is a high-pressure gas-discharge lamp which should replace the current incandescent lamps. HID lamps produce twice as much light as the halogen lamp. The (structural) advantage here is that existing headlights can be made considerably smaller and therefore take up less space. As a result the front area (of passenger cars) can become more streamlined. HID lamps also consume less power. One (technical) disadvantage with this type of lamp is that it takes a relatively long time (approx. 2 s) to attain maximum luminous flux.

Research is being conducted in order to find out whether or not application of the HID lamp is a favourable development for road safety and, if so, to what extent. This research is based on earlier SWOV publications on vehicle lighting and study of recent literature on HID lamps.

The state of affairs with regard to the development of HID lamps is that the product is in fact finished; various committees are in the process of drawing up draft regulations which will have to be approved on an international level at a later date.

Completion of this report has also been made possible by the annual contribution from the Nederlandse Vereniging van Automobiellasseuradeuren (the Netherlands Association of Automobile Insurers) (NVVA).

We wish to thank the English Department of Transport, Vehicle Standards and Engineering Division for giving permission to publish their translation of the original Dutch report.



# 1. Introduction

Road users require a certain amount of visual information on their surroundings to enable them to enter traffic. It is of secondary importance whether these road users possess a means of transport (car, bicycle etc.) or not (pedestrians). Both categories must be able to follow the road and avoid collisions with obstacles or other road users. In other words, you need to see and be seen on the road.

If there is inadequate natural light (in the evening, at night, in bad weather conditions) street lighting and vehicle lighting play an important role in the visual information system. Good street lighting is an effective way of making it safer to travel at night; so is the application of road-markings and the marking of obstacles along the road as well as vehicles and pedestrians if necessary.

This report shall discuss all aspects relating to passenger car headlights which are connected with road safety. Street lighting and markings shall only be discussed indirectly in this report.

With reference to vehicle lighting, we can distinguish between illumination (lighting up objects) and indication (marking objects). 'Objects' refer to both fixtures and road users. We shall describe the concepts of illumination and indication in more detail in terms of the observation process.

## 1.1. The observation process

Observation means that information is conveyed to the observer by the object of observation. It is only significant if the observation can be 'of use' to the observer. 'Perceptible' is the global indication that the object is 'visible'. Perceptibility is the collective term for the following four specific concepts:

*visible* (detectable): the relevant object can be seen: its presence can be determined;

*conspicuous*: the object stands out amongst other (competing) objects;

*identifiable*: it is possible to determine the category to which the relevant object belongs;

*locatable*: the location and also the (relative) characteristics of motion are perceptible.

## 1.2. Illumination

Illumination refers to making objects visible. Illumination by means of headlights is fundamentally different to illumination by means of public street lighting. In the case of public street lighting, where the illuminance on a vertical surface is not usually high (take pedestrians, for example), objects show up as dark silhouettes against a relatively light background. With motor vehicle lighting the illuminance is on the illuminated vertical surface as a result of which objects appear light against a darker background.

If a single car is driving along a public road, illumination of the road and objects poses hardly any problems. Thanks to modern lighting technology,

the main beam can easily produce a light intensity which illuminates a sufficient stretch of road when driving at a speed of more than 150 km/hr. If there is other traffic on the road, it is a different story. The light intensity aimed 'over the horizon' must then be drastically reduced in order to prevent dazzle. Switching to dipped headlights reduces the visibility of objects to just tens of metres so that only relatively slow speeds are acceptable. From a technical point of view, a compromise must be reached with dipped headlights between illumination on the one hand and the prevention of dazzle on the other.

HID lamps can produce considerably more light than the 'usual' double-filament anti-dazzle and halogen lamps. With the HID main beam (= high beam) illumination is therefore more than sufficient and of no interest to this study. Indeed there are problems with dipped headlights which need to be looked at more closely. We will come back to these later on in the study.

### 1.3. Indication

Indication refers to the ability to identify a vehicle. The vehicle must stand out amongst numerous irrelevant objects. Firstly, the presence of a vehicle must therefore be made clearly distinguishable: we call this 'marking'. Secondly, it must be made known that we are dealing with a vehicle which is able to perform all kinds of manoeuvres. For this purpose the vehicle is fitted with extra features especially to convey information. For example: white light indicates the front and red light the rear. Thus the information to be conveyed is coded. This is what we call 'indication'. If high-intensity marking lights are used, the indicating effect is reduced or even cancelled out as a result of glare. For this reason the HID main beam is not suitable for indication. We shall therefore only deal with indication in connection with dipped headlights from now on.

### 1.4. Single quantities of light

The following quantities are used in this report.

*light intensity*: the intensity of the radiated light beam (candela [cd]);

*luminous flux*: the total radiated quantity of light (lumen [ $\Phi$ ]);

*illuminance*: the quantity of light on a surface (lux [ $\text{lumen/m}^2$ ]);

*luminance*: the quantity of light reflected and brightness of a surface ( $L$  [ $\text{cd/m}^2$ ]);

*conversion*: 1 lux per 25 m = 625 cd

## 2. Function and application of dipped headlights

### 2.1. Engineering

We have already said that with dipped headlights objects must be illuminated on the one hand and dazzle must be prevented on the other. The ideal dipped headlight has a high light intensity just below the horizon so that the road, road users and obstacles are effectively illuminated a long way in front of the car and a low light intensity just over the horizon so that high-placed traffic-related features (signs etc.) can be observed but oncoming traffic is not dazzled.

The dipped beam is generally made up of one of the two spirals from a double-filament anti-dazzle lamp; the other spiral forms the main beam. In the double-filament anti-dazzle lamp, a metal cap is placed under the dipped spiral so that, provided that it is aligned properly, relatively little light is emitted above the horizon. With the help of the cap a reasonably sharp distinction (cut-off) can be achieved between low and high light intensity. In addition, the cap is sloping on one side so that the cut-off on the right-hand side is at an angle of  $15^\circ$ . This is what we call an asymmetrical dipped light beam which is compulsory for European vehicles. In the United States no separate incandescent lamps are used in the headlights but there is talk of an integrated headlight system (sealed beam). The dipped spiral is placed right in the focal point of a parabolic reflector; this produces a directed beam with parallel rays. On account of the structure of the spiral, the cut-off is less sharp than in the case of the double-filament anti-dazzle lamp. As a result of using prisms in the lens, the light beam focuses on certain locations more than others.

The American dipped headlight produces higher light intensity above the horizon than the European double-filament anti-dazzle lamp. One drawback with the double-filament anti-dazzle lamp is that incorrect alignment has a greater effect on the degree of dazzle than in the case of the 'sealed beam' system.

With halogen lamps you can create more luminous flux with constant power consumption and the same operational life compared with the conventional incandescent lamp. That is because the spiral can glow at a higher operating temperature and therefore has a higher light intensity. Despite the fact that the halogen lamp has a greater light intensity than the usual lamp, capacity increases considerably from 45/40 W to 60/55 W (main or dipped beam respectively).

As a result of making passenger vehicles more streamlined, headlight lenses are being placed more and more at an angle. In practice it seems to be difficult to meet lighting requirements with sloping lenses. The industry has tried to change the lighting requirements but without success.

In the case of dipped headlights, the glass of the headlight housing serves as a lens which provides the desired diffusion and asymmetry of the light beam. A prism system is fitted in the lens for this purpose. Asymmetry means that there is an extra focusing of light to the right, approximately on the horizon; the so-called 'hot spot'. To the left of this the beam is directed below the horizon in order to prevent dazzle. To the right of this

the beam is directed just above the horizon. Therefore a greater stretch of the road and verge is illuminated on the right-hand side.

A number of years ago BOW, amongst others, brought a new type of dipped headlight onto the market, the so-called Polyellipsoid Headlamp (PES) (see Figure 1). This is a separate dipped beam unit - not combined with the main beam with an effect which is comparable with a slide projector.

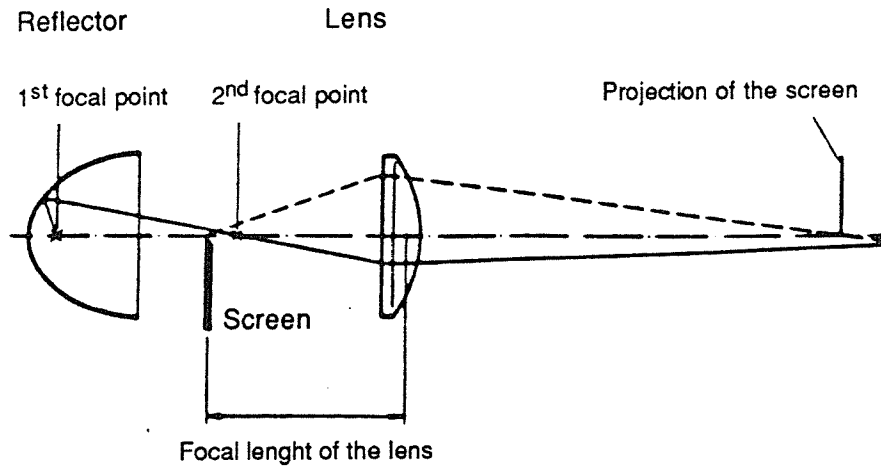


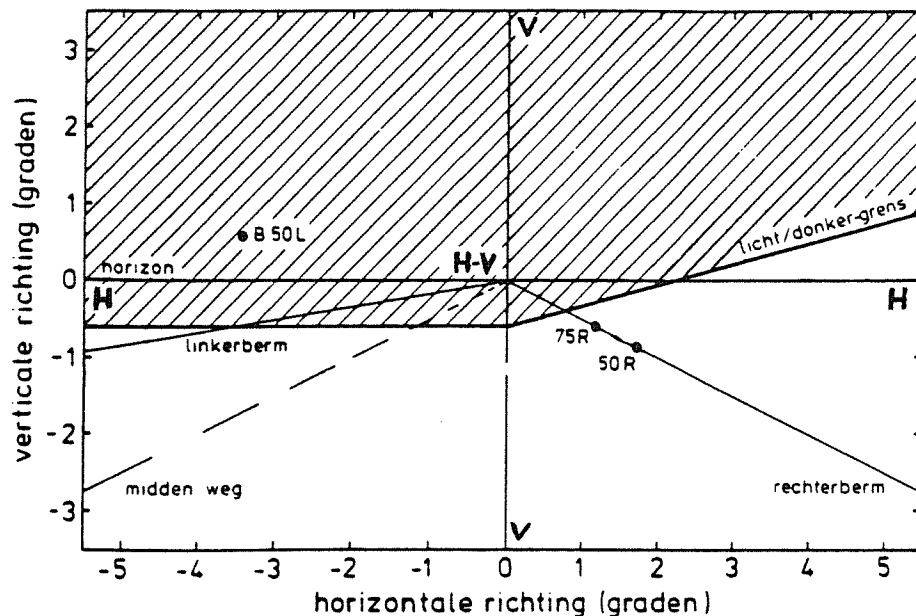
Figure 1. *Diagram of the Polyellipsoid Headlamp (PES). The top of the screen is shaped so that the projected dipped light beam slopes upwards on the right-hand side (Source: Lindae, 1985).*

In the unit there is a curved screen, the top of which has the required cut-off, and a lens with a relatively small diameter (60 mm). The screen is projected on the road surface, so to speak. The light source consists of a halogen lamp. The main advantage of this system is that a better distribution of light can be achieved either in accordance with existing specifications or in accordance with modified specifications to be developed.

Lindae (1985) stated that very sharp cut-offs can be achieved with Polyellipsoid Headlamps. However tests have shown that this can pose problems for drivers. Contrast seemed to be too great: the hard line dividing light and dark jumped about too much with the movements of the vehicle. As a result the lamps have therefore been modified and produce a less sharp cut-off.

## 2.2. Distribution of light from the dipped light beam

The beam of light from the dipped headlight must meet internationally accepted requirements. The light from the beam is distributed using a measuring screen with two principal axes; the horizontal H-H line with the V-V line through the centre HV (see Figure 2).



verticale richting (graden) = vertical direction (degrees)  
 horizontale richting (graden) = horizontal direction (degrees)  
 horizon = horizon  
 licht/donker-grens = boundary between light and dark  
 linkerberm = left-hand verge  
 rechterberm = right-hand verge  
 midden weg = middle of the road

Figure 2. Distribution of light from a dipped light beam shown from the perspective of the road surface. Point B50L is at eye-level for the oncoming traffic and points 50R and 75R are located on the right-hand verge at 50 and 75 m respectively (Source: Alferdinck, 1987).

A grid shows further angular divisions in degrees. The screen also has various points of measurement, for example point B50L which corresponds with a point situated 50 m in front of the car at eye-level for the driver of an oncoming vehicle. Either minimum or maximum lighting values are specified for the various points of measurement. In the area above the cut-off the light must comply with a certain maximum value in order to prevent dazzle. (As yet) no minimum values are recorded in the regulations for this purpose. In practice sufficient light to be able to read signs placed above the road seems to be emitted above the cut-off. The asymmetry of the light beam is clearly shown in the diagram.

By order of the American Motor Vehicle Manufacturers Association (MVMA), Sivak et al. (1992) produced an overview of numerous recent proposals for different distributions of light from the dipped light beam. These are compared with current American, European and Japanese lighting requirements. In order to be able to determine what the distribution of light should comply with, the following aspects have been drawn up regarding functional visual requirements for the dipped light beam.

*Above the horizon*

- illumination of road signs (and signposts) on the right-hand verge);
- illumination of signposts above the road;
- preventing the dazzling of oncoming traffic;
- preventing dazzle by traffic in the inside rear-view mirror;
- restricting the scattering of light in relation to atmospheric conditions (rain, fog, etc).

*Illumination at a distance of more than 25 m*

- illumination of the right-hand verge;
- illumination on broken ground.

*Foreground illumination (at a distance of up to 25 m)*

- illumination of the right-hand verge;
- homogeneity of the beam (aesthetics and comfort-related aspects);
- dazzle by light reflected by the road surface in rain.

*Other*

- reliability of visual alignment;
- effects of incorrect alignment.

On the basis of the above-mentioned aspects and the new proposals which were to be assessed, Sivak et al. (1992) stated that the functional requirements for dipped light beams are complex. It is therefore not surprising that each lighting requirement and each proposal has its own advantages and disadvantages. Researchers conclude that the proposals of the TNO Institute for Perception (IZF-TNO) (Padmos & Alferdinck, 1988); Alferdinck & Padmos, 1990) come closest to the functional requirements. If we compare these proposals with European lighting requirements, we notice the following: the TNO Institute for Perception's maximum light intensity 'above the horizon' is approx. factor 2 higher than European requirements. The minimum values 'below the horizon' are especially high compared with the other values. We will come back to this in the discussion.

Point/zone	ECE reg. R20	TNO Institute for Perception
<i>Above the horizon</i>		
Point B50L	max. 250 cd	max. 500 cd
Zone III	max. 440 cd	max. 1000 cd
<i>Below the horizon</i>		
50V	min. 3750 cd	min. 20,000 cd
50R	min. 7500 cd	min. 20,000 cd
75R	min. 7500 cd	min. 50,000 cd

Sivak et al. (1992) finally concluded that there is a lack of fixed criteria for evaluating proposals relating to visual requirements, eg with reference to the diffusion of light, the reflection of light by the road surface and the relation between illumination and dazzle, for example.

We will come back to this distribution of light when we talk about HID lamps and in the discussion.

### 2.3. Dipped headlights in traffic

We said that dipped headlights were important for illumination and indication. Dazzle is a negative aspect for fellow road users. These three aspects are illustrated in greater detail.

#### *Illumination*

With dipped headlights illuminated objects on and along the road must be made visible. In the previous paragraph we specified the requirements which light intensity must comply with. The approval tests are carried out in laboratories.

However in practice, measurements are carried out in the presence of oncoming traffic in order to determine visibility. A classic test involves comparing visibility when using the European double-filament anti-dazzle lamp system and the American 'sealed beam' system. It appears that when two cars with the same system meet, visibility is approximately the same. If there is a difference in the light intensity of the headlights - the weaker asymmetric dipped beam against the sharper light from the 'sealed beam' system - visibility is drastically reduced for the driver with the less powerful light. Moreover it appeared that visibility was usually minimal if the two cars were approximately 50 m away from each other.

More recent measurements confirm the results: when two cars with the same lighting system meet, visibility was always the same regardless of the type of system used. Another interesting test result was that visibility improved slightly if both oncoming cars had their main beam on instead of dipped beam.

Practical measurements with dipped headlights mostly involve the perceptibility of objects; this is expressed in terms of visibility. Identifiability and conspicuity are difficult to quantify.

#### *Indication*

If the (other) vehicle is moving, more information is needed than in the case of stationary objects. The additional information refers not only to the type of vehicle and direction of travel but also to the location, distance and above all the changes in the direction of movement which might occur within a short period of time. This is briefly defined by the indication of the vehicle. The dipped beam at the front of a vehicle performs this role. Therefore dipped headlights must meet specific requirements relating to number, location, configuration, the distance between vehicles, dimensions, light intensity and colour, for example. Most requirements are current so that we do not need to look at them in any more detail. However the size of the headlight and the light intensity are looked at more closely in the chapters which follow.

The lens surface of the dipped headlights used up till now generally has a diameter of approx. 15 cm; in this respect there is little difference between the conventional lamp and the halogen lamp. The dimensions of the lamp and distance between the two lamps shall be used in traffic to identify the vehicle category. If the surface of the lamp is small (as in the case of Polyellipsoid Headlamps with a diameter of 6 cm), it is questionable whether the dimensions of the lamp do help to identify the vehicle. Which leads us on to the following:

If the dimensions of a light source are too small to be perceived, it is called a 'point light source'. One of the consequences of this is that the perceptibility of the light (regardless of the colour) can be fully attributed in terms of the light intensity. This is defined for a point light source. In the study in question, it is important to know the potential magnitude of a light for it to still be considered as a point light source. Theoretical considerations based on laboratory experiments produce small dimensions. In practice it seems that lights which cover an angle of 10 angular seconds can still be considered to be point sources. 10 angular minutes correspond to 1 cm per 3.5 m which means that a light with a diameter of less than 5 cm must be considered to be a point source for all distances above 15 m. In this case the *dimensions* of lights of this type could hardly be used as a means of indication. The Polyellipsoid Headlamp with a diameter of 6 cm is only just above this. In traffic only the distance between the lights of two oncoming vehicles is likely to be used as a characteristic for identifying vehicles. In the case of vehicles fitted with Polyellipsoid Headlamps, this distance is comparable with vehicles with a conventional lighting system.

We can conclude that the size of the headlight is not likely to lead to problems concerning indication.

It was found that the actual light intensity cannot be used as a dimension for coding. Let us take the rear lights of passenger cars as an example: with individual observation, it is often difficult to distinguish between rear lights and rear fog lights. However differences in intensity are easy to observe if the intensity is *altered*; compare the brake light with the rear light, for example.

Let us take the front of the vehicle as another example: the difference in light intensity between motorcycle headlights and moped headlights is too small to mark a distinct difference between the two vehicle categories.

We can conclude that the *light intensity* of front lights can hardly be used as a means of indication. Excessive light intensity above the horizon may even mean that coded information is lost altogether.

Some researchers are convinced that it is better to reduce the intensity of dipped headlights where there is effective public street lighting; this makes vehicles easier to identify. Also, in connection with residential precincts, it is often said that car dipped headlights are not a suitable means of vehicle lighting; a marking light should be sufficient.

### *Dazzle*

If the light intensity of dipped headlights above the horizon (particularly on the left) is too high, it makes it difficult for the oncoming traffic to obtain visual information. This is what we call dazzle.

By aligning dipped headlights correctly, dazzle can be kept below an acceptable level. In the past, research carried out in the Netherlands has shown that approximately one third of headlights have been aligned incorrectly. Measurements carried out in various European countries in 1971 showed that 80% of cars caused more dazzle than the permissible statutory limit. A study conducted in the Netherlands in 1986 showed that things had got even worse: only 12% of passenger cars complied with the standard for intensity of dazzle (Alferdinck et al., 1986).

Loading and whether or not the fuel tank is full affect the height of



dipped headlights. Dirty or damaged headlamp glass and rain on the glass cause excessive radiated diffusion of light as well as dazzle. Light reflected by a wet road surface can also help to cause dazzle.

Alferdinck (1987) showed that cleaning one's headlights has a very favourable effect on the intensity of dazzle at point B50L (eye-level for oncoming traffic). Considering that many lamps had been set too low, the degree of dazzle would be reduced still further by setting them correctly. Cleaning had a lesser effect on the light intensity on the right-hand verge (points 75R and 50R); on the other hand, correct alignment had a considerable effect.

The ageing of the headlight seemed to have a great effect; it seemed that older lamps had a higher light intensity than new lamps. 80% of new lamps complied with the standard for intensity of dazzle at point B50L and only 39% of old lamps (both measured with a voltage of 12 V).

In addition to the intensity of light from the oncoming traffic and surrounding illumination, the degree of dazzle also depends on the accommodation of the organ of sight, the lateral distance from the oncoming traffic and the number of oncoming vehicles visible at the same time.

The 'De Boer scale' is often used to determine the degree of dazzle. This is a 9-point scale which goes from point 1: glare unbearable to point 9: glare just noticeable. The mid-point of the scale is point 5 with the assessment: 'just acceptable'. Olson and Sivak (1985) found that the degree of discomfort caused by dazzle is rather different depending on whether it is measured in the laboratory or in practice. For example, an illuminance of 1 lux (625 cd at 25 m) was assessed as 3.5 on the 'De Boer scale' in the laboratory whereas during a field study it was given the more favourable value of 5.5.

In the last few years more attention has been paid to determining the degree of dazzle and illuminance from car headlights in practice. Rys et al. (1992a and 1992b) developed a system which could be used to take measurements along the road both on a temporary and permanent basis. Points can be taken which correspond with the standard requirements for distribution of light from car headlights.

We can conclude that an extremely high number of headlights do not comply with lighting standards; dirt on the glass and ageing or damage to the headlight are individual causes. If the alignment of the lights could be improved in daily practice, the degree of dazzle may be even more serious. It speaks for itself that 20% of the new headlights did not meet standards in the study carried out at the Institute for Perception. (Oddly enough) headlights only have to comply with the standards for illuminance in the type approval test. If this approval is refused once, a tolerance is applied in subsequent checks which (depending on the point of measurement) can go up to approx. 30% (see also later in Section 3.3).

## 3. HID lamps

### 3.1. Engineering

In principle there are two methods (principles of physics) for light sources which can be used on a daily basis, namely:

- thermal incandescent lamp
- gas-discharge lamp.

We shall restrict ourselves to the gas-discharge method.

If you send a surge of electrical current with sufficiently high voltage through a gas (actually a vapour), this does in fact mean that you are sending a powerful flow of electrons through the gas. These electrons may collide with the atoms in the gas; if sufficient energy is transferred during such a collision, that atom will become excited ie one or more of the electrons circling the nucleus end up in a higher energy band. *Ionisation* may also occur; ie an electron totally breaks adrift and is expelled. The energy required to do this is supplied by the current surge; therefore excitation or ionisation can only occur if the current surge is sufficiently powerful.

If a proportion of the gas is ionised, two things happen. Firstly, the electrical resistance of the vapour decreases and secondly, the excited atoms quickly return to their original state (ground state) because the higher energy state for the relevant temperature is not stable. Upon returning to ground state, all the energy taken from the current surge is radiated back in the form of a photon. The wavelength of the wave which corresponds with this photon decreases as the energy difference between the excited state and ground state increases.

If you select the gas (vapour) carefully, you can ensure that the radiation is radiated in a wavelength range which is 'usable' for the organ of sight. In the case of gas-discharge lamps the spectrum is less continuous than in the case of incandescent lamps. In particular 'red' is under-represented.

Increasing the vapour pressure has a number of consequences. Firstly, the ignition voltage (the voltage for the first surge of current required to start the gas discharge) increases. In the case of lamps with very high pressure, the ignition voltage is around ten thousand volts.

Because the electrical resistance after ionisation is much lower than in ground state, a lower current and lower voltage is sufficient to maintain the gas discharge. Because the resistance characteristic is negative, (a larger current leads to a smaller resistance), it is necessary to insert a current limiting device in the electrical circuit. In principle an Ohmic resistance is sufficient but in view of a high output and stable radiation of light, all kinds of electronic circuits are used. These circuits are called the choke, or ballast. The ballast is often integrated with the starter: a device which supplies the first surge of high-voltage current. Figure 3 shows the circuit diagram with the relation between start-time and light intensity.

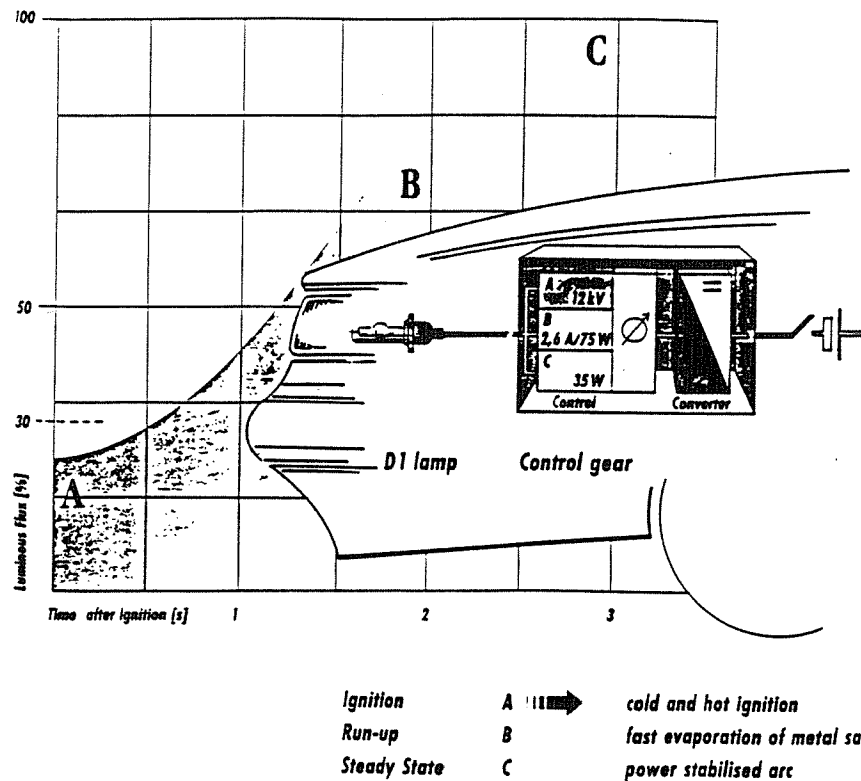


Figure 3. Circuit diagram for the HID unit (lamp and choke) with the relation between start-time and light intensity (Source: VEDILIS, 1990).

HID lamps are superhigh-pressure sodium lamps. The geometric and photometric characteristics of the light source are the basis for the characteristics of the light beam which it produces. The technical advantages of the light compared with the halogen lamp H1 are: higher luminance combined with smaller dimensions make it possible to achieve the same beam characteristics using a smaller optical system. As a result of the lower lamp capacity, the headlamp has a smaller thermal load.

The lower thermal load makes it possible to use plastic lenses and plastic reflectors in the headlights. This makes for a more controllable beam (less diffusion of light in the lens).

For individual technical details on the HID lamp, see the table below.

Characteristics	Incandescent lamp (H1) (with 13.2 V)	HID lamp
Average luminance	2000 cd/m <sup>2</sup>	6000 cd/m <sup>2</sup>
Capacity (incl. ballast)	68 W	45 W
Luminous flux	1550 lm	3000 lm
Luminance efficiency	25 lm/W	85 lm/W
Colour temperature	3200 cd/m <sup>2</sup>	4500 K

Source: VEDILIS (1990).

The larger specific luminous flux is an advantage: 3000 lm with 45 W against 1550 lm with 68 W. There are no precise details regarding the operational life of the HID lamps. VEDILIS (1990) only specifies that the operational life of the HID lamp is longer than that of the car.

### 3.2. International research

The American activities involving HID lamps are being carried out as part of CIE research by Technical Committee TC4.22 (CIE: Commission Internationale de l'Eclairage) covering the following subjects:

- A1: aspects relating to colour and contrast
- A2: dazzle from light intensity and dimensions
- A3: relation between main and dipped beam
- B1: distribution of light the left-hand side
- B2: distribution of light on the right-hand side
- B3: height setting
- B4: illumination of the foreground and sides
- B5: illumination of roadsigns above the road

On a European level, the 'VEDILIS' project has been started as part of EUREKA research. The leading participants in VEDILIS, which stands for Vehicle Discharge Lighting System, are various European manufacturers of lamps and lighting components. Several car manufacturers are involved in the project as secondary participants. Several European research institutes are involved in carrying out more fundamental research. The test results from VEDILIS were discussed with a technical committee from the GTB in Brussels (Groupe de Travail Bruxelles, 1952) in November 1991. The discussions produced draft Regulation No XX (1992). This regulation was presented to the GTB at the beginning of 1993. The proposals will be heard by other international standardisation committees - like the said CIE. VEDILIS has laid down its findings in a final report (VEDILIS, 1992).

### 3.3. Distribution of light

Draft Regulation No XX (1992) presents a specific distribution of light from the dipped light beam which differs from ECE regulation R20 and the proposal by the TNO Institute for Perception (see Section 2.2) as follows:

Point	HID compared with ECE-R20	HID compared with TNO Institute for Perception
<i>Above the horizon 1)</i>		
B50L	25% higher	38% lower
Zone III	42% higher	38% lower
<i>Below the horizon 2)</i>		
50L	67% higher	73% higher
50V	100% higher	63% lower
50R	67% higher	38% lower
75R	67% higher	75% lower

1) lower or higher resp. than **maximum** values

2) lower or higher resp. than **minimum** values

Here it should be noted that the values relating to HID lamps are based on a vehicle voltage of 13.2 V. The ECE-R20 values are based on approx. 12 V which is the normal battery voltage. When the engine is running the voltage across the halogen lamps is 13.2 V; in the case of HID lamps we start with this high voltage. If the lamp voltage of 12 V is increased to 13.2 V, (as in the case of halogen lamps), the light intensity increases by approx. 35%. If we interpret the table shown above, this means that if a value for the HID lamp is 35% higher than the ECE-R20 value, the light intensity is level with the halogen lamp.

The above table shows that the light intensity proposed for HID lamps is more than 35% higher than current ECE requirements at almost all the points. Point B50L is an exception (at 25% this is not higher than 35%). Compared with the values from the TNO Institute for Perception, the values for HID lamps are lower except for point 50L. We shall go into this in more detail in the discussion.

### 3.4. Aspects relating to dazzle from HID lamps

Flannagan et al. (1992) determined the difference between HID dipped lights and conventional 'sealed beam' dipped lights in terms of the discomfort caused by dazzle in a field study (using stationary passenger cars). Using the same light intensity for both types of light, testers assessed the discomfort caused by dazzle using the De Boer scale which we described earlier. Light intensity was chosen as the variable. The study showed that if the lamps under test radiated the same intensity of light in the eyes of the testers, the testers experienced more discomfort from the HID lamps (see Figure 4).

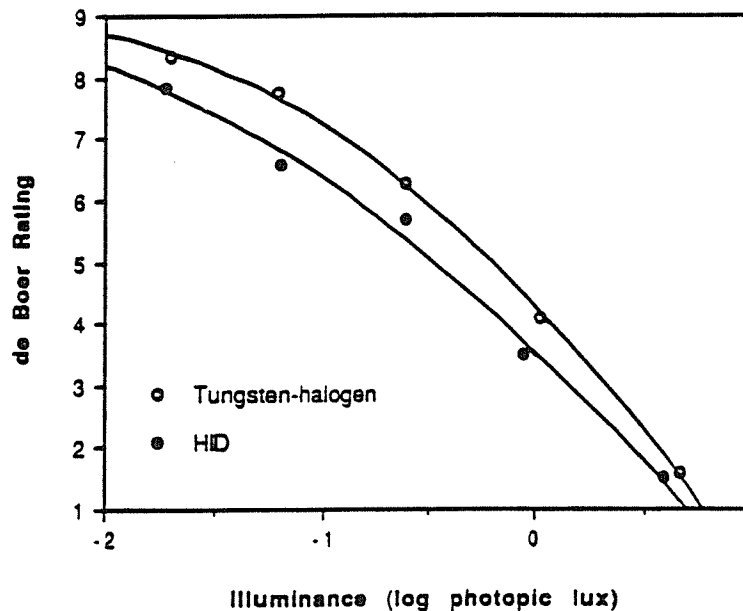


Figure 4. Assessment by testers of the degree of discomfort caused by dazzle as a function of light intensity. The lamps under test are an American halogen lamp and an HID lamp. The De Boer scale is used which goes from 1: glare unbearable to 9: glare just noticeable (Source: Flannagan, 1992).

In this practical test the discomfort was greater than predicted from laboratory tests. It is suggested that the difference between the results obtained in the field study and laboratory tests should not be explained until it is possible to predict the discomfort caused by dazzle from HID lamps in traffic.

Sivak et al. (1990) carried out a study on the effect of a small lamp area ( $45 \text{ cm}^2$ ,  $9 \times 5 \text{ cm}$ ) on the degree of dazzle. The background of this study was that a lamp with a smaller area has a higher luminance in  $\text{cd/m}^2$  compared with a lamp with a larger area with an identical photometric output. In physiological terms, a similar luminance should have more effect on the various human functions than the total quantity of light. This idea was based on an earlier study by Lindae which produced the recommendation that the minimum lamp area of (European) halogen dipped lights must be  $150 \text{ cm}^2$  in order to prevent dazzle. In the Sivak study a lens with an area of  $181 \text{ cm}^2$  is used for comparison. The light intensity was varied.

Researchers found that it only had a slight effect on dazzle: on a 9-point scale the degree of discomfort caused by dazzle from the lamp with the smaller area was only 0.2 points higher than the lamp with the larger area.

The effect of the smaller dimensions of the HID lamp on discomfort caused by dazzle was also studied as part of the European research project VEDILIS (Alferdinck & Varkevisser, 1991b; Vedilis, 1992). Discomfort was rated by means of laboratory experiments using the De Boer scale. The sources of dazzle consisted of rectangles with areas of  $3 \times 6 \text{ cm}$ ,  $6 \times 12 \text{ cm}$  and  $12 \times 24 \text{ cm}$ . Angles of dazzle of  $1.72$  to  $6.84^\circ$  were selected (corresponding with observation distances of 25, 50 and 100 m). The luminance of dazzle in the eyes of the observers varied from 0.03 to 3 lx.

The dimensions of the source of dazzle were found to have a slight but significant effect. If the dimensions of the source of dazzle were decreased by a factor of 2, the discomfort caused by dazzle increased by 0.1 points (on a 9-point scale). This increase can be compensated by reducing the light intensity of the lamp by 11%. Age and sex were found to have no effect on the degree of discomfort caused by dazzle. However there was found to be a correlation between age and 'disability glare'. There seemed to be a link between the dimensions of the headlight and the angle of dazzle: with small angles the effect of the dimensions is greater than with large angles.

Four other studies have been carried out on dazzle from HID lamps as part of the VEDILIS research project.

1. It was suggested that vehicles with low suspension, in particular, require a lower light intensity at 50 m (the 50L point) than prescribed by current standards (Rendu, 1992). This recommendation needs to be verified and has therefore not been adopted within draft Regulation No XX (1992).
2. In order to prevent dazzle on bends and via rear-view mirrors, the light pattern should be Z-shaped on the right-hand side of the HV point (Rumar, 1992). This line is located  $1^\circ$  above the horizon for which a limit of 3750 cd applies. It should be mentioned that the Z-shape has been adopted within draft Regulation No XX (1992); however no value is given in the table for the range below the  $1^\circ$  line above the horizon.

3. In order to prevent excessive discomfort to oncoming traffic caused by reflection from the road surface directly in front of the car and excessive differences between the luminance the area in front of the car and the area above the cut-off, two desirable maximum values are given: 15,600 cd at 25 m and 6250 cd at 10 m (Schmidt-Clausen et al., 1991). A maximum value of 12,500 cd is given in draft Regulation No XX for light intensity in the foreground.

### 3.5. Other aspects

The conspicuity of the front indicator combined with the presence of the HID lamp was studied by the TNO Institute for Perception (Alferdinck & Varkevisser, 1991a). During the study the lateral distance between the indicator and the HID lamp was varied from 0 to 40 cm. The light intensity and the size of the area was also varied for each type of lamp. Conspicuity was measured in a laboratory situation by determining the maximum sideways angle at which the indicator was still perceptible. Three light intensity ratios ( $I_{\text{indicator}}/I_{\text{headlamp}}$ ) were studied: low (0.03), average (0.31) and high (3.4).

It seemed that the conspicuity of the indicator was high if sideways angles were sufficiently large for the 'average' and 'high' light intensity ratios; the distance between the lamps hardly had any effect. The size of the lamps was only found to have an effect with the 'low' light intensity ratio.

## 4. Possible special applications of HID lamps

With the use of HID lamps as vehicle lighting, two possible applications are of interest. The first involves polarised light. When this was developed, only the conventional light sources were available. Fairly large lamp capacities are required for the application of polarised light. At that time this was felt to be a drawback in financial terms. Now with current efforts towards energy-saving lighting, this is just totally unacceptable. With the introduction of HID lamps the situation has changed considerably: the relative light output of HID lamps is so high that polarised light has 'suddenly' become a workable proposition.

The second (as yet theoretical) application involves the use of UV radiation from HID lamps. This radiation is invisible. However if the radiation comes into contact with fluorescent material, it becomes perceptible.

### 4.1. Polarised light

We use dipped headlights for vehicle lighting and try to achieve a compromise between 'a high degree of illumination and a low degree of dazzle'. As we said, this just leads to less illumination and/or unacceptably strong dazzle.

However there is an alternative whereby extremely generous illumination can be combined with almost total lack of dazzle: the application of polarised light. The idea behind the system of polarised light is an old one; the first publications date back to the 1930s (see eg Chubb, 1937). Also, a lot of research has been carried out which has resulted in a report issued by the OECD which discusses almost all theoretical and practical aspects relating to the application of polarised light for vehicle lighting (OECD, 1976). Although the OECD report offers a number of ready-made methods for application, as well as a number of strategies for introduction, and even describes experiments, the idea has never been developed further.

#### *Polarised light for car headlights*

Light is a wave phenomenon where the waves are transversal, i.e. the direction of vibration and direction of transmission intersect each other. Any direction of vibration is possible. All directions of vibration can be broken down into two mutually perpendicular areas which means that light waves can be polarised. By placing a 'polariser' in the light beam, you can ensure that only light which vibrates in a certain direction is transmitted. The other light, which is therefore perpendicular to the direction of vibration, is absorbed. Because the light is broken down in two directions, half of the total light energy is absorbed in this process.

If another polariser (usually called an 'analyser') is then placed further along the light beam, the quantity of light transmitted through the system by these two polarisers in combination depends on their mutual position. If the analyser is positioned in such a way that light is transmitted in the same direction as the polariser, then no 'extra' light is absorbed; the transmission with the two filters together is the same as the transmission with just the polariser (half of the incidental light). However if the direction of vibration transmitted by the analyser is perpendicular to the direction of vibration transmitted by the polariser, then no more light at all is trans-



mitted by the system. The light which is able to pass through the polariser is stopped by the analyser and the light which is able to pass through the analyser is stopped by the polariser beforehand.

This is now used in the application of polarised light for car headlights. A polariser is placed in front the headlamp; all the radiated light is therefore polarised. For the most part the light is 'depolarised' by the irradiated objects in nature; it becomes 'natural' light again. If you then place an analyser before the eyes of the oncoming traffic (the 'observer'), where the direction of light transmission is perpendicular to the direction of light transmission of 'our' car's polariser, then light from the lamp which goes directly into one's eyes cannot pass through the polarisers; therefore the lamp appears to emit no light. However the *depolarised* light which is reflected by natural objects (at least half of it) is transmitted by the analyser. In this way we can develop a system in principle which enables us to come close to achieving a compromise between 'a high degree of illumination and a low degree of dazzle'.

#### *Practical application*

Polarisers must be placed in front of the headlamps. These may be dipped lights with an HID lamp applied in such a way that the light output with filter is the same as the output of a 'normal' dipped light without filter. Analysers must be placed before the eyes. In principle this can be achieved in various ways but practice has shown that for car drivers who do not wear glasses, the simplest solution is to fit a narrow strip of polarisation filter at the bottom of the sun visor. For drivers who wear glasses, cyclists and pedestrians, it is preferable to attach a narrow strip of filter material to the top of their glasses. It should also be attached to helmet rims. In all cases it should be a narrow strip such that the road and traffic can be observed below the filter; you should only look through the filter when oncoming traffic is approaching.

If the headlamps with polariser produce the same light radiation (in terms of intensity and distribution) as regular dipped lights, an analyser is not directly necessary as surroundings look the same as they would if there was no polarised light at all. However people who use analysers have the advantage of reduced dazzle with the same observation potential.

If we consider a flexible introduction of polarised light, it means that the system 'with' polarised light must look exactly the same as the system 'without'. This is only practicable if the beam of light from the dipped lights is polarised and if the polarised dipped light meets all statutory and non-statutory specifications and regulations currently met by normal (non-polarised) dipped lights. In view of the loss of light in the filters inherently associated with the polarisation filter system, this is only workable with HID lamps in practice.

Extensive cost studies have been carried out and these are summarised in the said OECD report (OECD, 1976). Of course these details on costs need to be revised.

We can conclude that with the development of the HID lamp, the possible applications for polarised light have increased. In view of the necessary

practical drawbacks (use of polarisation filter, for example) there is no obvious general application as yet.

#### 4.2. UV radiation

In this report we have already discussed the fact several times that there are clear indications that one of the leading causes of increased traffic hazards at night is the reduced possibilities for visual perception. Factors such as rain and fog reduce perceptibility even more.

In addition to public street lighting, markings are an effective way of making it safer to travel at night. However the marking of objects is only effective if the relevant object is easier to perceive with the marking than without. It is often necessary for the object to be visible as well as the marking; the role of the marking is often to catch and direct one's attention (Schreuder, 1985).

At present retroreflective materials are used for substantial improvement of the perceptibility of markings when illuminated by headlamps. Retro-reflection means that the light is reflected almost exactly in the direction from which it has come. Markings are clearly visible, especially at long distance, because the light source (the headlamp) and the observer are close to each other. One drawback with retroreflective materials remains that an intense light source is required (which may cause dazzle).

It may be possible to improve the situation using HID lamps. We can make use of a characteristic of HID lamps which was not one of the original development objectives, but rather a sort of 'spin-off': the fact that HID lamps emit a considerable amount of ultraviolet (UV) radiation. UV radiation is invisible. However if the radiation comes into contact with fluorescent material, the radiation is converted in such a way that the wavelength of the 'returning' light is longer. If the wavelength falls within the 'visible' range, the radiation can be perceived.

##### *Visibility by using UV radiation in traffic*

In principle UV radiation offers interesting possibilities: the 'illumination' is invisible but the 'reflection' is. That means that above the cut-off or, where appropriate, above the horizon, a lot of UV radiation can be emitted without any dazzle. This principle which has been around for a long time has become the basis for efforts to apply UV radiation in road traffic with a view to improving perceptibility (of pedestrians, for example).

Because UV radiation is only effective if the irradiated objects fluoresce, UV radiation can never replace 'normal' lighting. At best UV radiation can enhance perceptibility. In view of the usual unfavourable observation conditions in road traffic at night, this can only be a good thing. However it means that all objects which need to be made easier to perceive must be fluorescent. A big problem is posed by the fact that by day, the objects are exposed to the (substantial) proportion of UV in daylight. Current technical developments are such that we know of no fluorescent materials which are able to retain their fluorescent effect for more than two to three years when subjected to this kind of long-term irradiation. Current retro-reflective materials easily last 10 to 15 years.

UV radiation is not altogether harmless (see the following section). If you simply use an HID lamp as the 'light source', for reasons of safety the UV radiation must be filtered. If it is used as a source of UV radiation, emission of the UV radiation must, of course, be allowed. UV radiation is divided into three ranges relating to its effect on the human organism (the photobiological effect), each with its own influence. An overview is given below.

UV range	Wavelength range	Photobiological effect
C	100 - 280 nm	strong
B	280 - 315 nm	strong
A	315 - 400 nm	weak

Short-term exposure to UV radiation from ranges B and C is acceptable provided that the dose is not too high. Only range A may be permissible for longer periods of exposure which is to be expected in the case of vehicle lighting. This means that the largest and most effective proportion of the radiation emitted by the HID lamp must be filtered. It is true that the end result is reasonably safe (not absolutely safe) but the effect in terms of potential fluorescence is rather slight. In short, an HID lamp with a 'safety filter' is not an effective source of UV.

We can conclude that with HID lamps becoming available, there has been renewed interest in the application of UV radiation in road traffic. We conclude that UV radiation seems to offer certain possibilities as a means of improving perceptibility - without increasing dazzle. However because an extra lamp is needed in addition to the existing lamps and fluorescent materials are also needed in addition to the existing retroreflective fittings, there seems to be no obvious short-term practical application.

## 5. The effect of UV radiation on health

In principle, HID lamp technology, which is based on a gas discharge in a vapour at very high pressure, can put road users or garage workers at risk under certain circumstances.

We can distinguish between two aspects. Firstly, the high voltage which is needed to ignite the lamp; namely 12,000 V. This seems to be more dangerous than the ignition voltage of a petrol engine (voltage approx. 20,000 V) where there are peak voltages. By providing sufficient insulation, this aspect seems to present no danger.

The second aspect concerns the considerable quantity of UV radiation from an HID lamp. The Board of Health (1986) issued a recommendation regarding the consequences for health of extensive use of devices and light sources which emit UV radiation. The following is taken from this report.

Exposure to UV radiation is expressed in the irradiation intensity ( $\text{W/m}^2$ ) and the irradiation dose ( $\text{J/m}^2$ ).

UV radiation causes reddening of the skin and increases the risk of skin cancer. Exposure of the eyes to UV radiation causes inflammation of the cornea and conjunctivitis if a threshold dose is exceeded; a connection between UV radiation and the occurrence of cataracts is suspected.

A skin/eye radiation dose of  $30 \text{ J/m}^2$  ( $1 \text{ W/m}^2$  per 30 s) is recommended as the limit for exposure over a period of one day. When the eye is exposed to UV radiation for years (spectral range 315-400 nm) a guide value of  $1 \text{ W/m}^2$  must be operated for cataracts.

In its report, the Board of Health also specifies that the UV radiation emitted during normal use of incandescent lamps and fluorescent tubes does not lead to perceptible biological effects. On the other hand, acute effects are not ruled out in the case of gas-discharge lamps if the outer casing is damaged.

IRPA guidelines (International Radiation Protection Association, Duchene et al., 1991) also specify  $1 \text{ W/m}^2$  per 30 s max. as the maximum daily limit for exposure to UV radiation. These values apply to unprotected eyes and skin.

Regulation No XX (1992) on HID lamps contains a chapter on UV emission. Firstly it suggests that the components which are responsible for reducing the UV radiation must be inseparable from the lamp as a whole. Also radiation in the wavelength range 200 - 400 nm shall not exceed the value of  $0.15 \text{ W/m}^2$  (measured at a horizontal distance of 25 cm in front of the lens). Considering the criteria specified, this value seems to be acceptable.

We can state that under normal circumstances, most of the UV radiation (according to standards) in the lens of the headlamp is absorbed. However if the lens is broken, the radiation can escape and may cause injury. The potential danger appears to be slight as if the glass breaks, the lamp usually breaks too.

## 6. Discussion

The use of HID lamps for the main beam (high beam) is not considered to be problematic. They can produce considerably more light than the normal double-filament anti-dazzle and halogen lamps so that if there is no oncoming traffic, the road and surroundings can be illuminated more effectively. Use of the dipped beam in road traffic is more critical. In particular, with the dipped beam, we need to reach a compromise between providing the best possible illumination on the one hand and preventing dazzle on the other. This discussion shall address both aspects. Indication (in this case marking the vehicle by means of illumination) does not seem to be problematic when HID dipped headlights are used as long as there is no dazzle.

The light intensity of the dipped beam must comply with lighting requirements (ECE Reg. 20). Study of the literature shows that there is little agreement between the various institutes which have carried out research into the distribution of light intensity of the dipped beam. Sivak et al. (1992) conclude that there is a lack of fixed criteria for determining light intensity values on account of interference relating to the diffusion of light (due to dirt and ageing), on account of reflection via the road surface and lack of clarity regarding the relation between illumination and dazzle. We can add to this the alignment of the headlamps which changes with load. It has also been found that results obtained in the laboratory differ from those obtained from measurements carried out on the road.

A study by the TNO Institute for Perception showed that 20% of new headlamps did not comply with standards. One explanation for this could be that headlamps only have to comply with the standards for light intensity in the type approval test. After that a tolerance of up to approx. 30% is applied in subsequent checks which is a very generous tolerance indeed.

Let us take another look at the light intensities to the left and right of the central H-V point proposed for HID lamps (Regulation No XX, Draft, 1992). Current ECE standards act as a reference. Recent values from the Institute for Perception are also used as an American study (Sivak et al., 1992) found these to come closest to (American) functional requirements (Padmos & Alferdinck, 1988; Alferdinck & Padmos, 1990).

The light intensity on the left-hand side of the central H-V point (both above and below the cut-off) is responsible for dazzling oncoming traffic on the left-hand side. Above the cut-off this is the light intensity at eye-level for the oncoming traffic (point B50L). With the introduction of the halogen lamp, the light intensity at this point is increased more or less "silently" by 33%. Draft Regulation No XX supports this level (312 cd at 13.2 V). According to the TNO Institute for Perception, a maximum value of 500 cd is still acceptable for this point. This is based on American and Japanese figures on the one hand; on the other hand it is specified that current light intensities come out considerably higher than ECE standards (Alferdinck & Padmos, 1990).

In the case of dazzle by oncoming traffic, the 'actual' light intensity is important for the visibility of objects. Experiments have shown that the discomfort caused by dazzle where two vehicles have the same light inten-

sity does not lead to reduced visibility. However differences in light intensity do: drivers of vehicles with headlamps with a lower light intensity are at a disadvantage compared with oncoming traffic with headlamps with a higher light intensity. In order to prevent excessive differences in the future (cars with and without HID lamps), it is preferable to choose a light intensity which is not higher than 312 cd in each case, in accordance with draft Regulation No XX.

The light on the left-hand side *below* the cut-off can also be a significant cause of dazzle in certain circumstances. Consider this: incorrect alignment, diffusion of light due to dirt on or damage to the lens, from reflection via the road surface and from vertical vehicle movements caused by uneven road surfaces and slopes. The points which lie in this field are 50L and 75L. In practice, point 75L, which is somewhat higher than 50L, seems to provide no critical values; that is because this point is in the light/dark area which may be why no standard is given for this point in draft Regulation No XX.

Therefore above all, point 50L is important with regard to the dazzling of oncoming traffic. The TNO Institute for Perception proposes a value for light intensity which is still slightly lower than current ECE standards (max. 9375 cd). With a voltage of 13.2 V, this light intensity is approx. 12,500 cd. The value of maximum 15,625 cd given in draft Regulation No XX is considerably higher. In order to reduce the degree of dazzle as much as possible in the circumstances outlined, it is proposed that current ECE standards should not be exceeded in each case.

In the case of light intensity on the right-hand side of the central H-V point, it is also a question of finding a compromise between the prevention of dazzle and sufficient visibility. Dazzle caused by oncoming traffic may occur on right-hand bends (car with HID lamps turning to the right in this case). The car ahead can also be dazzled via the rear-view mirror. In order to prevent dazzle, Rumar (1992) determined that light intensity at  $1^\circ$  above the horizon should not exceed 3750 cd.

If we are dealing with relevant visibility on the right-hand side, we are talking about points which lie below the horizon. These points are important to enable us to follow the road over a long distance, for example, and see (unlit) objects such as pedestrians and markings. The two relevant points for distribution of the dipped light beam 50R and 75R. Current ECE standards specify minimum values of 7500 cd. The TNO Institute for Perception specifies values which are substantially higher: minimum 20,000 cd for 50R and minimum 50,000 cd for 75R. These values are based on the visibility of objects at a distance of 110 m at a speed of 80 km/hr. Draft Regulation No XX specifies a value of 12,500 cd for each of these two points. There is a lot to be said for values higher than those specified in current ECE regulations. Above all, if (a certain degree of) dazzle is caused by oncoming traffic, it is important to have sufficient light intensity on the right-hand side in order to be able to perceive pedestrians and cyclists on the right-hand side of the road, for example. On the other hand, there are also dangers involved. Firstly, higher light output can lead to higher driving speeds which is undesirable, especially on single-lane roads with mixed traffic. Furthermore, if light intensities are considerably higher, dazzle can occur if there is dirt on the lens, incorrect alignment, reflection from the road surface etc. We need to consider that higher light intensity for cars does not help weaker road users (cyclists and pedes-

trians as oncoming traffic and intersecting traffic); their ability to perceive objects is drastically reduced when dazzle is involved.

Current ECE standards specify minimum values (7500 cd) for cars for the right-hand point at 75 m. Practical measurements carried out by the TNO Institute for Perception have shown that only 15% of cars meet this ECE requirement (Alferdinck et al., 1986). With regard to light intensity on the right-hand side of the H-V point, we can determine that a higher value is therefore to be recommended at point 75R, for example. Considering the drawbacks given for third parties, the question is whether the minimum value of 50,000 cd should be as high as proposed by the TNO Institute for Perception.

On the basis of the above, we can conclude that it is not easy to make a definite choice regarding the light intensities of the various points of distribution of the dipped light beam. Literature gives the impression that the emphasis is on attaining higher light intensities in order to enhance observation at greater distances. As long as light beams are misaligned and there is an excessive amount of diffused light, this will continue to be a drawback.

With regard to the light intensity requirements for HID lamps, it is proposed that a conservative draft should be selected first of all. After more insight is obtained into the scope of the negative aspects outlined, the requirements can be revised. The (difficult) realisation of technical solutions such as an automatic alignment system for the dipped light beam and an appropriate system for cleaning the glass of the headlamps also affect this revision. Moreover the results of American activity as part of CIE research into HID lamps may throw new light on the problem and should be awaited.

HID lamps probably have an advantage over conventional lighting as far as the ageing of the lamp is concerned. In particular, experiments have found that ageing of the incandescent lamp contributes to a higher degree of dazzle. We may assume that this is not so much the case with HID lamps so that the light intensity is more constant with time.

Another advantage of HID lamps is that, broadly speaking, higher light intensity is possible which favours the detection of cyclists in side-streets, for example.

In laboratories it has been determined that the small area of HID lamps produces slightly more dazzle than conventional incandescent lamps. However practical research in America has shown that the discomfort is considerably greater. It still needs to be taken into consideration that the comparison is based on the American 'sealed beam' lamps which all produce a higher degree of dazzle than European headlights.

In the case of gas-discharge lamps, the colour red is under-represented which can cause problems with the perception of red reflectors. We are still waiting for the results of tests in this field which have been carried out in America.

On account of the high intensity of light from HID lamps, the potential applications of polarised light for vehicle lighting have increased. On account of the necessary practical drawbacks, (use of polarisation filters, for example), there is no obvious general application as yet.

This also applies to the use of UV radiation in road traffic. Indeed it can be used to enhance perceptibility but various features are required: an extra UV lamp in addition to existing lamps and fluorescent materials in addition to existing retroreflective materials.



## 7. Conclusions

The proposed distribution of light from the dipped light beam of HID lamps is higher than current ECE standards at virtually all points of measurement. This has two negative aspects for road safety: firstly the observation potential of the other party (oncoming traffic and intersecting traffic) is reduced and secondly, the driver is able to see a greater stretch of road which may be attended by higher speeds. Incorrect alignment and dirt produce diffusion of the beam from current headlamps. It is expected that this problem will be intensified by HID lamps.

The application of HID lamps has one advantage with regard to road safety: broadly speaking, improved distribution of light is possible. As yet the other advantages are technical and vehicle-related: smaller area, more effective light output as a result of which less power is needed (less power consumption).

We can draw the conclusion that the application of HID lamps must be discouraged until the level of light has been reduced and the problems regarding the diffusion of light have been solved.

A general reassessment of the function of vehicle lighting is desirable on account of road and traffic conditions which have changed considerably over the last few years. Consider residential precincts (the car as an equal partner) and trends for reducing the speed of motorised traffic. In this respect development of the design and use of vehicle lighting has been left behind.

## Literature

Alferdinck, J.W.A.M. (1987). *Oorzaken van hoge verblindingssterkten en lage bermlichtsterkten van autokoplampen*. IZF 1987 C-19. TNO Institute for Perception, Soesterberg.

Alferdinck, J.W.A.M.; Padmos, P. & Burrij, S. (1986). *Verblinding door autokoplampen; Een praktijkmeting*. IZF 1986 C-15. TNO Institute for Perception, Soesterberg.

Alferdinck, J.W.A.M. & Padmos, P. (1990). *Optimal light distribution of low beam car headlamps; A survey of recent literature*. IZF 1990 C-31. TNO Institute for Perception, Soesterberg.

Alferdinck, J.W.A.M. & Varkevisser, J. (1991a). *Conspicuity of the front direction indicator in combination with the D1 headlamp*. IZF 1991 C-20. TNO Institute for Perception, Soesterberg.

Alferdinck, J.W.A.M. & Varkevisser, J. (1991b). *Discomfort glare from D1 headlamps of different size*. IZF 1991 C-21. TNO Institute for Perception, Soesterberg.

Chubb, L.W. (1937). *Polarized light for motor vehicle lighting*. Quoted in OECD (1976).

Duchêne A.S.; Lakey, J.R.A. & Repacholi, M.H. (Editors) (1991). *IRPA-guidelines on protection against non-ionizing radiation*. Pergamon Press, New York.

Flannagan, M.; Sivak, M.; Gellaty, A.W. & Luoma (1992). *A field study of discomfort glare from high-intensity discharge headlamps*. Report UMTRI-92-16. Transportation Research Institute, University of Michigan.

Gezondheidsraad (1986). *UV radiation; Blootstelling van de mens aan ultraviolette straling*. The Hague.

Lindae, G. (1985). *Improvements of low-beam pattern by use of Polyellipsoid Headlamps (PES)*. SAE Technical Paper Series 850228.

OECD (1976). *Polarized light for vehicle headlamps*. OECD, 1976.

Olson, P.L. & Sivak, M. (1983). *Improved low beam photometrics*. Final Report. Report UMTRI-83-9. Transportation Research Institute, University of Michigan.

Padmos, P. & Alferdinck, J.W.A.M. (1988). *Optimale lichtsterkteverdeling van de gedimde autokoplamp*. IZF 1988 C-9. TNO Institute for Perception, Soesterberg.

Regulation No XX, Draft (1992). *Uniform provisions concerning the approval of motor vehicles headlamps equipped with gas discharge light sources*. Version J, September 2, 1992.

Rendu, R. (1992). *Influence of the 'sharpness' of the cut-off of a headlamp equipped with a gas-discharge light source (GDLS) on drivers*. VEDILIS Final Report. Eureka Project 273.

Rumar, K. & Helmers, G. (1992). *Forward intensities with respect to rear-view mirror glare*. VEDILIS Final Report. Eureka Project 273.

Rys, M.; Russell, E., Harwood, D. & Rys, A. (1992a). *Field studies with a Headlight Measurement System*. Paper prepared for the Transportation Research Board, 12-16 January 1992.

Rys, M.; Russell, E., Harwood, D. & Rys, A. (1992b). *Development of a Headlight Measurement System*. Paper prepared for the Transportation Research Board, 12-16 January 1992.

Schmidt-Clausen, H.J.; Damasky, J. & Wambsganss (1992). *Foreground illumination, comfort aspects and reflected glare on wet roads*. VEDILIS Final Report, Eureka Project 273.

Schreuder, D.A. (1985). *Toepassing en gebruiksmogelijkheden van retro-reflecterende materialen in het wegverkeer; Een overzicht van de stand van zaken*. R-85-62. SWOV, Leidschendam.

Schreuder, D.A. & Lindeijer, J.E. (1987). *Verlichting en markering van motorvoertuig; Een state-of-the-art rapport*. R-87-7. SWOV, Leidschendam.

Sivak, M.; Simmons, C.J. & Flannagan, M. (1990). *Effect of headlamp area on discomfort glare*. *Lighting Research and Technology* 22 (1990) 1.

Sivak, M.; Helmers, G.; Owens, D.A. & Flannagan, M. (1992). *Evaluation of proposed low-beam headlighting pattern*. Transportation Research Institute, University of Michigan.

VEDILIS (1990). *Eureka Project 273*. (Brochure, edition unknown, year estimated).

VEDILIS (1992). *VEDILIS Final Report*. Eureka Project 273 VEDILIS Directorate, Secr. Philips International BV.