

VEHICLE LIGHTING WITHIN BUILT-UP AREAS

Motor vehicle front lighting on roads with public lighting

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Dr. D.A. Schreuder

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Institute for Road Safety Research SWOV, The Netherlands

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## SUMMARY

One of the questions confronting both the policy makers and scientific researchers concerns the most suitable lighting for vehicles on roads with (fixed) lighting systems. Especially when the lights at the front of the car are involved, this question proves to have many facets.

In the early years cars carried no lights regulated by law. With the increase in traffic density came the problem: glare caused by oncoming traffic. The solution was sought and partly found in two directions: on the one hand the road lighting, which already existed for purposes of public safety, was adjusted to meet the requirements of motorised traffic, and on the other hand a lighting system was fitted to cars which struck a compromise between ample illuminating and little glare, viz. a headlight (country beam) for normal use, and a low beam used only for short periods when passing oncoming traffic (passing beam). However, as a result of the constantly increasing traffic density, road users must to an increasing extent rely solely on their car lights.

This result from the basic fact that the technical facilities in use now and in the near future mean that the driver requires a great deal of visual information for this purpose about his surroundings. In the dark, artificial lighting is needed to enable the driver to obtain this visual information. Such artificial lighting can be divided as follows: the marking and signalling of objects and their characteristics, and directing the light on to objects.

The object of signal lighting is twofold. Firstly, the presence of the relevant objects has to be marked. Secondly, all sorts of characteristic aspects of the relevant object have to be signalled. Which aspects are most important depends on such things as the traffic situation, but the ones usually involved are: the nature, position and speed of the object, the changes it makes and, above all, the expected changes; also its conspicuousness against its background, especially as regards the risk of it being confused with other objects.

The illumination speaks for itself in this respect.

The considerations given in the report indicate that when road lighting is present (even very poor road lighting), low-beam headlights can make only a small, and mostly negligible contribution to illumination and thus to the visibility of objects. There are two exceptions: firstly, when the objects have a high reflecting power (are reflectorised) and, secondly, when short distances of observation, and therefore low speed differences are involved. Furthermore it follows that glare from the low-beam headlights of oncoming traffic disturbs perception in all normal night-time situations.

This means that low-beam headlights are not adequate as a "means of illumination", and are in fact not very suitable for use inside built-up areas. The very much weaker side lights are, of course, entirely unsuitable as a "means of illumination". In contrast to low-beam headlights, which are both a "means of illumination" and a signal light, side lights are solely signal lights.

From the considerations given in the report, several conclusions are drawn:

1. Normal low-beam headlights used at present cannot be regarded as an optimum compromise between "illuminating a lot" and "dazzling little", particularly on busy (urban) roads provided with lighting.
2. Side lights of the current types are mostly too weak to serve as signalling lights though there has been a clear improvement in recent years.
3. The optimum light for the front of motor vehicles to be used on lit roads should have an intensity which is lower than present low-beam headlights, but higher than present side lights. It is suggested that the minimum luminous intensity should be at least 20 cd, and the maximum not more than about 100 cd.
4. An improved side light or "city beam" can clearly boost the visibility of objects fitted with reflectorised material. In other respects, however, its contribution to visibility is slight or non-existent. The visibility should be ensured by a road lighting system that will meet the necessary requirements.

5. The luminous intensity may be considered to be the best possibility for coding. Colour is scarcely suitable for more detailed coding, as red is generally used to mark the rear of cars, and yellow is in many instances reserved for direction indicators.

6. The combined use of low-beam headlights and side lights was formerly regarded (and rightly so) as a very great drawback, and often as a major hazard. The improvements made to side lights in recent years have made this problem less acute. The question now is whether the combined use of low-beam headlights and "city beams" should still be regarded as a major drawback.

As a final conclusion it is therefore stated that:

The "city beam" can be regarded as the most suitable (and perhaps as the only realistic) solution to the question of what type of lighting should be considered optimum for the front of cars on lit roads. This is linked to the proviso that the road lighting should meet specific minimum requirements.

On the basis of the data available at present the optimum technical design for the city beam can be described as follows:

- a. The present low beam is reduced in power. The preferable construction is that in which the luminous flux of the lamp is reduced; the luminous intensity straight ahead should be at least 20 cd, but not more than about 100 cd.
- b. The change-over from the low-beam headlights to the "city beam" is achieved by switching.
- c. Suitable for developing further is the system of automatic, stepless, gradual dimming, particularly if the automatic device needed for this purpose can also be used for switching other lights e.g. the vehicle rear lighting.

Finally, it should be kept in mind that introducing the "city beam" will take considerable time. Usually, the general use of low-beam headlights during the transition time is considered as the most appropriate compromise; one should keep in mind, however, that such temporary general use of low beams should not hamper the ultimate introduction and usage of the "city beam".

## 1. INTRODUCTION

One of the questions confronting both the appropriate authorities and scientific researchers concerns the most suitable lighting for vehicles on roads with (fixed) lighting systems. Especially when the lights at the front of the car are involved, this question proves to have many facets. A completely satisfactory answer to this question cannot be given as yet; however, we shall indicate in the following report the directions in which a reasonably applicable answer can be sought.

The attempts to find an answer will be preceded by a description and a more detailed specification of the actual problems. In view of the form in which the relevant question is often, though not entirely rightly, posed (viz. should side lights or low-beam headlights be preferred), we shall start our analysis of the problem on the basis of some historical considerations.

In the early years no lights on cars were required by law. Any lamps on the vehicle were meant to illuminate a short stretch of the road ahead. With the increase in traffic density came the problem: glare caused by oncoming traffic. The solution was sought and partly found in two directions: on the one hand the road lighting, which already existed for purposed of public safety, was adjusted to meet the requirements of motorised traffic, and on the other hand a lighting system was fitted to cars which struck a compromise between illuminating a lot and dazzling little: the low-beam headlight. Moreover, the use of the incandescent filament lamps, which could be switched on and off quickly, made a double lighting system possible, viz. a headlight (country beam, high beam, long beam) for normal use, and a low beam used only for short periods when passing oncoming traffic (passing beam, short beam, dipped headlight).

Both these lighting systems (road lighting and car lighting) were found to provide acceptable solutions. However, the constantly increasing traffic density resulted firstly in new roads being

built at an increasing pace and, secondly, in the fact that the costs of adequate road lighting came to be looked upon more and more as a (sometimes too heavy) burden on public spending. The result is that, as the traffic load grows, road users must to an increasing extent rely solely on their car lights. In the following report we shall investigate the problems caused by this trend and discuss what solutions can be achieved over the short or medium term.

To analyse these problems we must start by dealing with the function that "traffic facilities" - in the widest sense of the word - have for road users: this function can be described as "to offer road users the possibility of reaching the final destination of their journey safely, quickly and comfortably, and at minimum cost".

Some comments can be made on this description, particularly on the threefold objective, viz. reaching the final destination safely, quickly and comfortably. Of these three, safety can be regarded as a necessary, though not a sufficient, precondition for a "good" traffic flow, with the reservation that absolute safety is not felt to be a necessity. In other words: society accepts the fact that a very high safety level is achieved, although it might still be possible to prevent even more accidents. Speed and comfort are preconditions that the road user usually considers very important. Speed and comfort also form an important basis on the design and construction of many other traffic facilities. And here comfort must be taken to mean something other than pure luxury.

In the following the emphasis will be on the safety aspect, because - apart from the obvious need for a reasonably safe traffic situation - it has been found that as regards the present problem, the facilities aimed at raising speed and improving comfort follow the same trend as the safety facilities, yet are even more far-reaching. It should be noted, however, that this is by no means self-evident; for instance, the driving characteristics of vehicles and also certain requirements of comfort (and sometimes of speed),



which are dictated by economic considerations, are sometimes opposed to the safety requirements.

## 2. THE FUNCTION OF LIGHTING

To reach his destination safely the driver must be able to follow the road, and must collide with nothing on the way. The technical facilities in use now and in the near future mean that the driver required a great deal of visual information for this purpose about his surroundings (the road, the areas alongside the road, obstacles, other vehicles, pedestrians, etc.).

In the day-time this information can generally be obtained with reasonable ease; in the dark, however, artificial lighting is needed to enable the driver to obtain visual information. Such artificial lighting may have two aspects, viz. the marking and signalling of objects and illuminating objects. The word "object" is used here collectively, and covers pedestrians, stones, curbs, and also road markings and road signs. Signalling is normally achieved either by fitting a specially designed lighting system to the object to be perceived or by providing it with reflectorising elements. These will be discussed later.

The object of signal lighting is twofold. Firstly, the presence of the relevant object has to be signalled. This sets some requirements as regards the light intensity and position of the marker lights, but sets none as regards colour, configuration, etc. Secondly, several characteristic aspects of the relevant object have to be signalled. Which aspects are most important depends on such things as the traffic situation, but the ones usually involved are: the nature, position and speed of the object, the changes it makes and, above all, the expected changes; also its conspicuousness against its background, especially as regards the risk of it being confused with other objects.

If the relevant object is a vehicle, special attention must be devoted to the need to be able to differentiate very clearly its front and rear, i.e. whether it is approaching or moving away. To signal these aspects a clear, unmistakable and detailed coding

system is required. Of importance is the fact that marking lights with a high luminosity may reduce or even render impossible the signalling function because of the glare they cause.

For the lighting of objects the two above-mentioned systems are both suitable: road lighting and lighting via car headlights. In both cases the principle is that a difference is created in luminance\* between the relevant object and its immediate background. The luminance of an object depends on the luminous flux striking that object and on the way this is reflected. Normal traffic obstacles, particularly pedestrians, usually have a low and diffuse reflection (Figure 1). Moreover, the most important part of the background is a part of the road surface that is a relatively long way behind the pedestrian (Figure 2). And, lastly, when road surfaces are viewed from a very low angle, they give a markedly specular reflection, even when dry (Figure 3).

Combining these three facts, we arrive at the following characteristics for the two lighting systems. In the case of road lighting, where the illuminance on vertical surfaces is usually rather low, almost all objects stand out as dark silhouettes against a relatively light background. Conversely, car lighting makes many objects - especially light ones - show up light against a dark background. For in this case the illuminance is strong on vertical surfaces facing the light source - and thus the observer. Therefore, the luminance is high even when there is a low reflection, whereas that part of the road surface situated further away and forming the background is hardly illuminated at all.

One special question involves the illumination of retroreflecting (reflectorised) objects. They reflect the light in a direction

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\* The luminance is the photometric quantity in which the brightness of luminous bodies is expressed. For a precise definition see e.g. Walsh (1965).

which (practically) coincides with, but is opposite to, the direction of incidence. Usually they have a high reflectivity.

The system of car lighting, where the light source (car headlights) and the observer (driver) happen to be close together, enables efficient use to be made of this phenomenon. Retroreflecting materials are available in several designs, such as glass beads in adhesive films, corner cubes, and "cat's-eyes" made from glass or plastic sections (see e.g. OECD, 1975). Using good materials a reflectivity of  $50-1000 \text{ cd/m}^2$  per lux can be achieved, depending on the construction.

The lighting function is discussed only briefly above, and not systematically. In particular, a number of fundamental aspects of visual perception are not dealt with. However, the present report would not seem to require a more detailed discussion; this is provided elsewhere by Asmussen (1972), Griep (1972, 1972) and Schreuder (1971a, 1974b).

### 3. THE OUTLINE OF THE REPORT

The function of lighting is twofold: (1) an effective signalling must be achieved, and (2) the illumination should be adequate, particularly for "random" objects on the road. Signalling is provided mainly by lights on cars, whereas illumination is provided partly by road lighting.

Cars are generally with a set of signal lights - in addition to the headlights meant for traffic-free roads and the low beams that are likewise intended for illumination. These signal lights are the front lights (side lights, parking lights, etc.), the rear lights, brake lights and direction indicators. These will be discussed later.

Of more importance, is the fact that the useful compromise reached in the 1920s will have to be abandoned in view on the radically changed traffic situation. Though the primary function of traffic facilities has not changed, a new solution still needs to be sought. At the moment it seems that - for roads with road lighting inside the built-up area - the solution must be sought in adapting the characteristics of present car side lights so as to meet certain quality criteria. To differentiate it from present side lights, the new-style version is referred to here as the "city beam". In the present report we shall discuss successively the considerations that have led to such a recommendation, the possible alternatives, the problems linked to the introduction and technical production of such a "city beam" and, lastly, the areas in which further research is required.

The first of the above subjects can be approached from two directions (though they both produce very similar answers): one can ask which is better, side lights or low-beam headlights, or one can ask what the optimum lighting is for the front of cars. The considerations based on these two approaches will be discussed in Chapter 4 of this report. The data on which these considerations are based are summarised in the Appendices. The discussion of the

alternatives in Chapter 5 is followed by a discussion of the consequences of introducing the "city beam", in which much attention is devoted to the fact that the (signal) lighting of cars forms part of one single system. In Chapter 6 some technical designs will be dealt with, each with its own specific advantages and drawbacks.

A description is given in Chapter 7 of the supplementary research that will have to be undertaken before "city beams" can be introduced; attention is also devoted to a number of factors which, though they call for no specific research work, are nevertheless of importance, especially for certain categories of road users. Finally, Chapter 8 contains an outline of a possible integrated lighting and signalling system for use in cars in the future.

At this place, reference is made to an Australian study (Fisher, 1974) which contains, apart from the report on a number of interesting experiments, a survey of the whole problem of vehicle front lighting. This survey and its conclusions are very similar to the report given here, although the publications have been prepared independently.

#### 4. CONSIDERATIONS LEADING TO THE "CITY BEAM"

##### 4.1. The "side light or low-beam headlight" approach

The question of whether it is better for traffic that cars use side lights or low-beam headlights on roads with fixed road lighting cannot be answered on the basis of accident statistics. A number of enquiries have shown that the accident pattern is hardly influenced, if at all, by the type of vehicle lighting (see Appendix A1). It has been found, though, that if there is an option, the choice between side lights and low-beam headlights depends on the quality of the road lighting. If the choice were left to the driver himself, the outcome would mostly be the combined use of side lights and low-beam headlights. In view of the clear improvements in side lights recently, it is doubtful whether the drawbacks of such a combined use should still be regarded as of importance (Appendix A2).

If we investigate the extent to which low-beam headlights are suitable for use inside built-up areas (and particularly the asymmetrical "E"-beams that are regulation in continental Europe present), then we find that their contribution to the visibility of objects is slight, and does not lead to a systematic improvement. If objects are fitted with retroreflectors, low-beam headlights give a much better result than present side lights. However, they do not differ much from the "city beam" as proposed in this report, especially when the visibility is expressed in terms of the visibility distance (Appendix A3). This advantage is in turn cancelled out to a considerable extent by the glare caused by oncoming traffic. Even with properly adjusted, clean and dry headlamps that comply with the regulation, the glare level is very high, particularly when a number of oncoming cars are visible at the same time (Appendix A4). If allowance is made for dirt, the aiming of the headlamps (Appendix A5) and so on, then it is found that, owing to all these influences, the glare is almost always higher than in the "ideal" case.

Furthermore, it is not likely that large improvements may be found (Appendix A6). This includes the application of halogene lamps.

This need cause no surprise: the light that induces glare is mostly scattered light, and scatter is aggravated by most of the above factors.

The first conclusion that can be drawn is that when road lighting is present (even very poor road lighting), low-beam headlights can make only a small, and mostly negligible contribution to illumination and thus to the visibility of objects. There are two exceptions: firstly, when the objects have a high reflecting power - retro(re)reflectors - and, secondly, for short distances of observation, thus with small speed differences.

The second conclusion is that glare from the low-beam headlights of oncoming traffic disturbs perception in all normal night-time situations. This disturbance may become intolerable in the case of poorly lit roads, heavy traffic, dirty headlamps, misaimed beams, etc. Although some improvement is possible using new constructions for headlamps these drawbacks are largely inherent in the very concept of "low-beam headlights".

These two conclusions show that low-beam headlights are not adequate as a "means of illumination", and are in fact particularly suitable for use inside built-up areas. Side lights, being much weaker, are, of course, entirely unsuitable as a "means of illumination". In contrast to low-beam headlights, however, which are both a "means of illumination" and a signal light, side lights solely serve as signalling lights. In considering the question "side lights or low-beam headlights?" much attention was devoted to their respective signalling characteristics, mainly on qualitative considerations. The large volume of quantitative research can best be described under the second approach mentioned above: "optimum vehicle lighting".

#### 4.2. The "optimum vehicle lighting" approach

##### 4.2.1. Introductory

We attempted above to find an answer to the question: "Are side lights or low-beam headlights to be preferred on a road with overhead road lighting?" A clear-cut answer was not found.



We shall attempt below to go further by trying to answer a question formulated in a somewhat different way: "What is the optimum lighting to be carried on the front of vehicles on roads with road lighting?" In answering this question we shall start with two points raised in the previous section, one stated explicitly, the other more implicitly. These points are (1) the contribution of present-type low-beam headlights to visibility is negligible, and (2) present low-beam headlights are brighter than is needed - and in many instances much too bright - in order to function optimally as signalling lights. In the further investigation into the optimum vehicle lighting, therefore, it will also be assumed that such lighting functions solely as a signal light, and that the illumination (visibility of objects) is provided in full by the overhead fixed road lighting. We shall return later to the economic aspects of this assumption, and also to the fact that the use of retro-flectors may form an exception (see para. 4.4. and Appendix A3). In a following section we shall also deal with the possibilities that exist for an optimum solution for unlit roads (para. 4.5.) and how the various solutions can be integrated within an overall system for vehicle signalling and lighting (Chapter 8).

By "signalling" we understand: putting across any message by means of a light signal. Often this message is in code. The possibility of decoding must be considered as part of the signalling system. In this sense, "marking" may be considered as a special case of "signalling" (i.e. signalling the presence, and nothing more). Signalling, taken in this sense, is a more complex problem than illuminating for the following reasons.

1. A number of variables may have to be signalled simultaneously to others.
2. Contrary to the problem of illumination, it is not always unambiguously clear in the case of signalling for whom the signals are meant - the only certainty is that they are not meant for the driver of the vehicle to which the signals are attached.
3. In the case of signalling all directions must be considered, and not only the front of the vehicle.

4. Particularly in respect of signalling towards the front of the vehicle, matters may be considerably complicated by the presence of (glaring) headlamps.

Both accident statistics (SWOV, 1969a, 1976b) and theoretical considerations (Griep, 1972; Roszbach, 1972, 1974; Schreuder, 1971a) show that it is obvious that motor vehicles present a major danger to each other. Furthermore it is evident that in order to try and reduce this danger not only the situation and position of all relevant objects (i.e. vehicles) at a certain time is important, but it is also extremely important that some sort of prediction should be made about the future position and changes therein. Furthermore, particularly in order to judge these future positions, more or less accurately, it is important to know broadly speaking the type of vehicle that is to be encountered. Therefore, the main characteristics that vehicles should signal to the drivers of other vehicles are:

- a. presence
- b. position
- c. speed, direction
- d. changes in speed and direction
- e. future (planned) changes in speed and direction
- f. type of vehicle (as regards size, category, and more in particular, modes of movement that can be expected from the vehicle e.g. turning circle, possible decelerations).

In the day-time some of these characteristics are quite obvious to other drivers. Nevertheless a number of them are obviously not perceptible, particularly planned changes in speed and direction that have not yet been effectuated. For this sort of information, some means of signalling is needed even in the day-time.

It is not practical, but not necessary either, to install a separate signalling light for each of the characteristics mentioned above. Marker lights transmit more information than presence alone. The position, but also speed and direction, and even to a certain

degree the changes in them can be assessed according the way the marker lights are observed. Marker lights (side lights, "city beams" and even low-beam headlamps) therefore have a wider signalling function than marking the presence alone. This contribution, however, means that is not feasible to set up functional requirements after each of the separate characteristics.

When considering an optimal vehicle front-lighting system, it is necessary to take into account aspects of signalling, even although the present report deals primarily with marker lights.

#### 4.2.2. Functional requirements of signalling lights

##### 1. Colour

It might be considered whether a light, as regards its signalling function, puts up any requirements as regards its colour. When one looks into this consideration, several points can be made.

In the first place, it must be noted that colour is not particularly suitable for primary coding (Roszbach, 1972; Projector et al, 1969; SWOV, 1975; Hargroves, 1971).

Secondly, the number of colours that can be discerned easily and securely enough for road traffic situations, is restricted.

McCormick (1964), as quoted by Roszbach (1972), indicated nine different colours, but when normal tolerances of manufacture, the capacities of colour defective observers, and the requirements regarding transmission of colour filters are taken into account, only six are left over, viz.: red-amber-(or orange)-yellow-green-blue-white. When some "safety margin" is built in, the number is even more restricted. CIE (1975b) suggests that orange, yellow and white should not be used in the same signalling system. Thus the number boils down to four, of which blue generally is restricted to police vehicles and the like.

It is sometimes suggested that one should apply the three colours left over for vehicular signalling lights in about the same way as for traffic signals, that is: green-proceed; yellow-warning; red-stop (Mortimer, 1969; Allen, 1970). This recommendation is

questionable because firstly a preceding vehicle is always an obstacle when one comes close, so that the green signal suggesting a free and unoccupied road is not justified. Furthermore, such systems are only suitable for the rear of vehicles.

Thus, the applicable colours for automotive signalling are reduced to red and white and/or yellow. It turns out that the colour difference between the normal white headlamps and the "selective" yellow headlamps as used a.o. in France is too small to be used as a coding mode, particularly not as a primary coding mode (SWOV, 1975). For any practical use, yellow and white can be regarded as similar for vehicular signalling. In practice, the colour is used in a very simple way, red means rear, and white or yellow means front. For other applications, the colour of signalling lights can be disregarded as a source of primary information. It might be added that this coding usually is not applied very systematically. So is yellow applied for direction indicators and also (sometimes at least) for brake light.

## 2. Luminous intensity

As indicated earlier, the applicability of signalling lights depends more upon the way in which it is notified than upon its visibility or detectability (SWOV, 1969a). Furthermore, the detectability usually is determined on the basis of threshold measurements, where 50% detection is used as a basis of discrimination between detection and non-detection - and this under laboratory circumstances. When putting up values for signalling lights that can be applied in practice, however, one may end up with completely different values.

Research on road traffic control signal lights indicated that lights of the size as usual on cars, may be considered as point sources. This means that they can be characterised by their luminous intensity alone (CIE, 1977a; Fisher & Cole, 1974).

In two respects it is important to consider the luminous intensity of signalling lamps. Primarily, one might search for the

optimum intensity for signalling lights in order to be effective also in other respect (such as the possibility to localise them). This has been investigated primarily by means of experiments involving subjective appraisals in more or less truly simulated traffic situations. The more important studies in this report have been summarised in para. 4.2.3. The end result is, as indicated already, that the minimum value of the luminous intensity should be about 20 cd, and the maximum about 100 cd. Another important question is, whether the luminous intensity in itself may be used as a primary code for signalling.

The use of the luminous intensity as such is often applied as a source of information, particularly when rear lights and brake lights are incorporated within one optical unit. However, it turns out that this practice is no good at all, particularly when one considers the fact that the luminous intensity is not very suitable as a primary dimension of coding. It turns out in practice that not the difference in intensity, but only the change-over from low to high intensity (or the reverse) is easily visible (Roszbach, 1972). On these grounds it is taken that the luminous intensity is not suitable as a primary dimension for coding. More in particular, this is not possible taking into account the rather small margin between some tens to some hundreds of candles that comes into consideration on other grounds. This implies that the as such important differences between mopeds and motor vehicles cannot be signalled alone by means of a difference in luminous intensity.

### 3. Dimensions and location

Primarily one might question how large a light should be before it is not perceived as a point source. Basic considerations lead to small dimensions in this respect (Anon, 1971a), but in practice a light of 10 minutes of arc seems to be considered generally as a point source (Janssen, 1972; as quoted by Roszbach, 1972). This corresponds with 1 cm at about 3,5 m, implying that a light of 5 cm diameter may be considered as a point source only for a

distance over 15 m. This means therefore that the dimension of lights is not particularly suitable as a primary mode of codification (see also Fisher & Cole, 1974).

The second aspect has to do with the distance between two signalling lamps. This distance is related more to the visual acuity, more in particular as described in the "minimum separabile" (Le Grand, 1956). Also here, a resolution of several minutes of arc seems to be most applicable for most practical circumstances. This means that two small lamps at an interdistance of some 10 cm may be easily seen as separate at a distance of some tens of metres. These considerations did lead to the well-known recommendations of separation of signalling lights with different functions (Mortimer, 1971; Hargroves, 1971; Projector et al, 1969). It seems however, that the interdistances does not have to be very large. This may be of importance to consider the distance between low-beam headlamps and front direction indicators, and between break lights and fog rear lamps.

We will not go into the question whether the distance between signalling lights can be used as a separate, primary dimension of codification.

A third point may be the configuration of signalling lights. Combined with the colour of the lights this is widely used in maritime traffic. The importance for road traffic is described by Roszbach (1972) particularly regarding the rear of the vehicle. Regarding vehicle front lighting the regularizing of the interdistance between the lights is of particular importance.

#### 4.2.3. The optimum value of the intensity for signal lights on the front of cars

##### 1. Trials conducted under the auspices of the GTB

In 1960 trials were conducted in Phoenix, Arizona, under the auspices of the GTB. From the (unpublished) results De Brabander

(1972) concluded that the optimum luminous intensity for "position lights" on the front of cars is 20 cd. These trials were conducted under favourable conditions and were also from a stationary position. Pocci (1970) listed slightly lower values; it cannot be ascertained exactly whether the same criterion was used for "optimum" and, secondly, whether it is exactly the same trial that is being described.

## 2. Trials in The Netherlands regarding signalling lights

In the 1950s a number of unpublished trials were conducted in The Netherlands. The findings did, however, play an important role in drafting NEN 3322, the Dutch Traffic Lights Standard. Although the conditions for signal lights for vehicles and those for road traffic are not the same, there is a considerable degree of concurrence, particularly as regards the recommended luminous intensities. For night-time situations NEN 3322 recommends: at least 25 cd, at most 200 cd (see NEN, 1972; Anon, 1973b). See also CIE (1977a).

Some of these observations concentrated more on side lights. In stationary trials on well-lit roads in clear weather Balder (1956) found that a luminous intensity of between 5 and 20 cd was usually sufficient.

## 3. Trials conducted by SWOV

As part of the "Side lights and low-beam headlights" investigation, the Institute for Road Safety Research SWOV conducted a number of investigations in order to study the relationship between the behaviour of pedestrians and the luminous intensity of the lights carried by a car. Details are given in SWOV (1969a). A brief summary of the findings is given below.

On a road of about 250 m length a car approached a number of observers. At a given distance a flap in front of the observers' eyes was opened for a moment. During the time that the flaps were open, the road and the approaching car were visible. The observers then had to indicate whether they would cross before the car arrived if

they imagined themselves to be at the edge of a 7 m wide one-way-traffic road. Apart from the decision (yes or no), the time taken to reach that decision was also noted. The variables used were: the distance between car and observers (between 45 and 155 metres), the speed of the car (30, 40 and 50 km p.h.) the luminous intensity of the car's signal lights (0.3, 3, 30 and 300 cd with identical light colour and light distribution) and the level of the road lighting (0, 0.2, 1 cd/m<sup>2</sup>). All 180 situations were presented in random order, each once to seven observers with normal vision, spread over two evenings. In addition, the 15 relevant day-time situations were shown.

The following conclusions were drawn from the trials (SWOV, 1969a):

- "1. In the experimental conditions, the decision whether to cross is not demonstrably related to the intensity of an approaching car's lights if this is greater than 0.3 cd and less than 300 cd.
2. In the experimental conditions the choice is not demonstrably related to the street-lighting level.
3. If the conflict conditions of lighted vehicle/crossing pedestrian are also influenced by the intensity of the car's lights then, by elimination of alternatives, this conflict is likely to result from the simultaneous appearance in the field of vision of vehicles carrying lights of very different intensities.
4. Conclusion 3 indicated a need for uniformity in vehicle lights. This is a subject for further research into optimum intensity and the width of the margin permissible around this optimum without detracting too much from uniformity. As already indicated the position of this optimum is determined firstly by the desire to have the highest possible intensity for maximum conspicuousness, and secondly by the desire for low intensity to avoid glare."

#### 4. Experiments in Australia

Fisher & Hall (1970) have described trials in which the responses of road users were studied with regard to improved side lights (here called town beams).

"The practical object of the experiment was for three vehicle



drivers by the subject (observer cars) to meet a simulated traffic stream of six vehicles approaching in the opposite direction. The two sets of vehicles were to meet and pass at one of two locations (meeting places):

- a. on the crest and bend of the road
- b. on a straight section of the road.

And under two headlighting conditions:

- a. using normal lower beam of the British/American type currently used in Australia, and
- b. using experimental town beam.

The experiment was carried out on two nights with twelve subjects each night. Each night was divided into two stages. Six of the subjects were paired off to act as drivers, the other six were to act as pedestrians. At the end of each six consecutive runs, a questionnaire was administered to drivers, passengers and pedestrians through which they gave their appraisal of comfort and visibility. At the end of each sub-stage a special detection run was made to find out whether a vehicle on town lights could be seen amongst a stream of vehicles on lower beam."

Some of the results may be summarised as follows:

"It was found that drivers and passengers answered in an essentially similar manner. The second questionnaire yielded almost identical responses to the first, showing the consistency of subject responses. There was no significant order effect in being first a driver, as against a pedestrian.

A majority of subjects (15/24) thought that the visibility of pedestrians was better with one system than with the other. Twelve out of the fifteen thought that this difference was marked or very marked. However, the fifteen were split 8/7, lower to town beam, in their estimation of which system gave the better visibility. This non-significant result is consistent with Jacobs (1968) that during vehicle meetings with conventional lights visibility will be generally adversely affected by headlamp glare, except that it may be enhanced in the final stages by increased illumination."

"Twenty-three out of the twenty-four subjects noticed the difference in brightness of the two system of headlighting. Twenty-two subjects thought the difference was marked or very marked."

"Seventeen subjects thought real vision comfort was much better with the town light."

"Most pedestrian subjects (23/1) felt more comfortable when facing the town beam than with conventional lights. Crossing the road was thought by eighteen subjects to be easier with one of the two systems. However, the 13/5 split for town over dipped lights is not significant. This is consistent with the results of Jacobs (1968) which suggests that pedestrian behaviour in crossing the road is independent of lighting."

"Discussion:

Previously it has been demonstrated that street lighting of the appropriate standard alone provided adequate visibility on traffic routes. Use of the conventional lower beam can adverse affect both visibility and comfort. Its replacement by some other form of lighting which is glare free but acts as a conspicuous marker of a moving vehicle has been suggested. A group of 24 road users, as a whole, preferred the use of a town beam (conventional lower beam reduced to 1/10 intensity) to the conventional lower beam in a well lighted street. The preference appears to be based on comfort considerations rather than on ones of visibility, and suggests that road users are critical of the use of lower beams in well lighted streets. This results gives support to the concept of vehicle lighting designed specifically for use on lighted traffic routes."

"Recommendations:

It is recommended that State Traffic Regulations should require

- a. the provision of town beams on all vehicles after a suitable lead time, and
- b. the use of town beams in all appropriately lighted roads."

## 5. Experiments in Great Britain

Fisher (1974) reported a number of experiments conducted at the University of Birmingham.

These requirements were related to the way, how vehicle marker lights were judged by observers on lighted streets. During the tests, the following variations were introduced: the average road surface luminance (between  $0.06 \text{ cd/m}^2$  and  $1.35 \text{ cd/m}^2$ ), the dimensions of the lights (diameter 178, 102 and 56 mm) and the luminous intensity in eight steps ranging  $10^5$  to 1 cd. This range included poor side light at the one hand and high beams at the other hand. Furthermore, some tests were conducted in a dynamic fashion. The judgements did include the "conspicuity" and the "discomfort glare".

The final conclusion of this study reads as follows:

"This and previous investigations suggest that marker lights are inadequately conspicuous and dipped headlights are too glaring for use on urban traffic routes lit with street lighting to the relevant standard. It appears, therefore, that a town light is necessary if both safety and comfort are to be provided for road users on lighted urban traffic routes. The optimum solution appears to be a light, based on the present headlights, giving a straight ahead intensity of about 80 cd. This conclusion is in agreement with that suggested by others (Jehu, 1965; SWOV, 1969a; Fisher & Hall, 1970). Such a light can easily be obtained and lighting uniformity ensured, by automatically dimming the dipped headlight beam."

### 4.2.4. Conclusions

The following conclusions may be drawn:

1. Colour is not suitable as a primary coding dimension.
2. Because red is nearly exclusively restricted to the rear of vehicles, only yellow and white are left for the vehicle front lighting.
3. The intensity of vehicle front lights - which serve as indicated

above more purposes than marking alone - should preferably be not lower than about 20 cd, and not higher than about 100 cd.

4. The dimensions and the position on the vehicle are not critical for the signalling function. This leaves ample room for the design of the signalling lights.

#### 4.3. ECE-enquiry

The ECE (Economic Commission for Europe), and more specifically its Working Party 20, held an enquiry in 1973 amongst the member states on the use of side lights and low-beam headlights inside built-up areas. Answers have been submitted by nine countries, viz. Austria (A), Denmark (DK), the Federal Republic of Germany (D), Malta (M), The Netherlands (NL), Poland (PL), the United Kingdom (UK) and the Soviet Union (SU).

The answers can be summarised as follows:

1. All countries have regulations on car lighting inside built-up areas.

The following possibilities were mentioned:

- a. side lights compulsory everywhere (DK);
- b. low-beam headlights compulsory everywhere (D);
- c. obligation to carry either side lights or low-beam headlights depends on the quality of the road lighting (M, PL);
- d. the choice between side lights and low-beam headlights is left to the driver (A, NL, UK, SU).

(Note: In many countries which were either not involved in the enquiry or have not responded, similar rules exist. For instance, France, Italy and Spain come under a.; the USA, Belgium, Australia and Japan under b.; and Norway, Sweden, Switzerland and Yugoslavia under d.)

2. In most cases the ECE-standards have been adopted for side lights (min. 4 cd, max. 60 cd) and for dimmed headlights ("E" or "H").

3. All countries have regulations in force on the position of the different lights. There is no uniformity. For instance, four countries stipulate a minimum height between 30 and 50 cm. The

regulation on maximum height in the different countries varies between 100 cm and 160 cm. Regulations also differ a great deal as regards the lateral position.

4. The enquiry did not yield any new data on the use of side lights and low-beam headlights. The data provided by UK and NL corresponded with the data in the literature (RRL, 1964; SWOV, 1969).

5. Nor did the enquiry responses bring any new data as regards the investigation into the correlation between accidents and vehicle lighting. This, too, is in line with the literature, particularly SWOV (1969a).

(Note: In addition to the answers to the enquiry, a further two studies made in the UK and Belgium should be mentioned. These are summarised in Appendix A1 together with SWOV, 1969a.)

#### 4.4. Present alternatives

Our concern here is to increase the visibility of objects relevant to road users, whilst reducing the glare caused at present by low-beam headlights. Apart from the above mentioned solution of "city beams" being used as signal lights in combination with effective road lighting to improve visibility, a number of other alternatives can be mentioned. In this section we shall discuss some alternatives which are frequently raised and which are often claimed to be applicable into practice immediately or in the near future. In para. 4.5. we shall discuss a few alternatives that cannot be made operational until some future date. Further studies are discussed in Chapter 7.

1. Improving road markings. This expedient may be of help for various elements of the "driver's function", particularly in helping him maintain his lateral position. If reflectorised road markings are used which remain effective over a lengthy period and even during rain and snow, this may contribute substantially to visibility. However, good road markings provide no solution, because some sort of head lighting is still required and also because they do not make obstacles visible. But they can certainly make an im-

portant contribution to visibility (see, for instance, Frédéric, 1972 or OECD, 1975).

2. One-way traffic. If it is possible by means of measures of traffic engineering or of road construction to obviate oncoming traffic (by one-way traffic systems, or by dual carriageway roads with a wide central reservation), then there is no direct glare. The brightness of car lights could be increased and hence the visibility. Allowance should, of course, be made for glare via rear-view mirrors. For unlit motorways a separate type of car light has been proposed in various countries (Wichert, 1971) or has even been put into practice. For normal roads this solution is unfeasible because of the heavy cost involved in setting up a one-way network, or doubling lanes, which also require a central reservation of more than about 10 m wide (Wortmann & Webster, 1968), or installing anti-glare screens.

3. Road lighting. Very good road lighting would solve all the problems of the visibility of objects. However, it is unsuitable as a general solution to the problem under review. Firstly, the level would have to be very high - the value of  $2 \text{ cd/m}^2$  recommended by the "Nederlandse Stichting voor Verlichtingskunde" for busy urban streets might perhaps be just sufficient (NSvV, 1975). However, it is more important that even under such conditions the moving vehicles should be fitted with signal lights (marker lights). There are many indications that even in broad daylight such marker lights are necessary, or at least highly desirable (see also para. 7.3.5.).

4. Signal lights on vehicles. The recognisability and localisation of vehicles can be greatly improved by using better signal lights. As far the rear of the vehicle is concerned, much research work has been conducted (see, for instance, Mortimer, 1969, 1970, 1971; Roszbach, 1972a, 1974). Less research has been done in relation to the front, but it has been found that glare caused by, say, low-beam headlights considerably reduces the signalling function.

On this basis it can be stated, as already indicated above, that low-beam headlights are themselves not suitable as signal lights (see, for instance, OECD, 1971 and Schreuder, 1966, 1971b). However, if no retroreflectors are fitted, signal lights do not make any perceptible contribution to the visibility of objects. Therefore no overall solution can be found along these lines, despite the fact that good signal lights are important for road users in general.

5. Retroreflectors. The more wide-scale use of better retro(re)flectors is useful when cars carry dimmed headlights. Signalling or pre-warning the presence of obstacles is possible (SWOV, 1969b, 1969c). However, this provides no general solution to the problem on hand, firstly because the problem of glare from low-beam headlights (or even high beams) still exists and, secondly, because non-reflectorised obstacles always remain a possibility.

6. Improved low-beam headlights. It is frequently claimed that different car-light constructions would solve the problem. Apart from the "city beam" recommended in this report (in combination with adequate road lighting), there seem to be no other possibilities even though some constructions may achieve a marginal improvement in some respects (see also Appendix A6).

a. The introduction of (duplo) halogen lamps brings a very slight improvement in visibility and a wider beam spread, though at the cost of higher glare (De Boer & Schreuder, 1969).

b. Rectangular car headlamps bring no significant improvement in visibility; their frequent use in Europe is perhaps more a question of "styling".

c. Vehicle stabilisation may help to prevent the glare from exceeding the permitted level in the case of low-beam headlights; of course, no reduction in glare as a whole should be expected (Gibié, 1970; Yerrell, 1971a).

Summaries of current ideas on possible ways of improving car lighting are given by De Boer (1971), Devaux (1970) and Farber et al. (1971). But no solutions are put forward.

#### 4.5. Future alternatives

In the future, especially over the long term, a number of alternatives are possible which might provide a good solution to the problem of vehicle lighting, both on lit and unlit roads. Most of the solutions mentioned here are reasonably feasible from a technical viewpoint. Some have been tested under laboratory-scale or pilot-scale conditions. In all cases, however, a considerable amount of research is needed to ascertain whether the systems are really suitable for practical application - partly in view of the costs they will involve. All this research will take a long time yet, which means that no solution can be expected over the short (at least over the next 5 to 10 years). This means that, even if one of the alternatives given below proves to be practicable, a solution will still have to be found over the short term. It is, of course, important that the "short-term" solution chosen does not conflict with the possibly preferable long-term one.

1. Polarised light. By fixing cross-linked polarising elements in front of the headlights and in front of the driver's eyes, it is possible to obviate glare almost entirely and to achieve a considerable increase in visibility. Technically, this system has nearly been worked out in full. But full-scale practical trials are still considered necessary. A proposal has been worked out in detail by OECD (1976b). However, in view of the high costs the trial will most probably not be executed in the near future. Descriptions of the system are given by Farber et al. (1971), Rumar (1970), Hemion (1968) and others. For roads outside built-up areas this system is generally considered to be very promising.

2. Movable headlamps. In some proposals a beam with a very sharp cut-off is regulated automatically by the light of an oncoming car so that the driver remains just outside the range of the beam and is thus not dazzled. This proposal can perhaps be developed into a useful system in the future; for the present, however, there are still many technical, legal and economic problems that need to be solved (Hicks, 1970).



3. Even further removed from being technically feasible is the use of "narrow band monochromatic light" and of "gated viewing". We shall therefore do no more than mention these possibilities.

4. A completely different approach is adopted in the research into the possibilities of switching off the visual system (wholly or partially) in providing information. Much research is being done in this field and extensive literature exists.

However, the full automation of traffic will take a great deal of time and money and will probably never be suitable for the greater part of the road network. All the partially automated systems that are considered to be actually feasible at the present time do, however, still require a considerable amount of visual information, which means that we can scarcely expect a solution to the problem being discussed in this report to emerge from this particular direction - at least not over the short term.

#### 4.6. Conclusions

1. Normal low-beam headlights used at present ("E", Anglo-American or halogen) cannot be regarded as an optimum compromise between "illuminating a lot" and "dazzling little", particularly on busy (urban) roads provided with lighting.

2. Side lights of the current types are mostly too weak to serve as position lights, though there has been a clear improvement in recent years.

3. The optimum light for the front of motor vehicles to be used on lit roads should have a luminous intensity which is considerably lower than present low-beam headlights, but higher than present side lights. Provisionally, a value somewhere in the range between approx. 20 cd and 100 cd seems the most suitable.

4. An improved side light or "city beam" can clearly boost the visibility of objects fitted with reflectorised material. In other respects, however, its contribution to visibility is slight or non-existent. The visibility should be ensured by a (fixed, overhead) road lighting system that will meet the necessary requirements.

5. Additional research is needed into the desired values for the "city beam" and the most suitable road lighting. More data are given in Chapter 7. These show that the supplementary research need not be very extensive.

6. The luminous intensity may be considered to be a good but not the most important coding dimension. Colour is scarcely suitable for more detailed coding, as red is generally used to mark the rear of cars, and yellow is in many instances reserved for direction indicators. Furthermore, the differences between yellow and white appear to be too small for these colours to be used in coding (SWOV, 1975). Green and blue are hardly suitable, if at all. The dimensions and the position of signal lights are of lesser importance. We shall return to this when we discuss the technical designs (Chapter 6).

7. The combined use of low-beam headlights and side lights was formerly regarded (and rightly so) as a very great drawback, and often as a major hazard. The improvements made to side lights in recent years have made this problem less acute. The question now is whether the combined use of low-beam headlights and "city beams" should still be regarded as a major drawback.

8. Experimental research points to the fact that pedestrians and drivers evaluate vehicle lighting in a similar way. In view of the lack of data, it may not be concluded that this applies to all pedestrians, e.g. to children and old people as well.

9. A number of alternative answers can be given to the question as to the most suitable vehicle front lighting for lit roads. Apart from the "city beams" in combination with adequate road lighting, however, not one of these alternatives is suitable for general application over the short term. All alternatives either provide a solution merely for certain sub-aspects, or are not generally applicable, or should be regarded as projects for the (distant) future, or the costs they would incur are excessively high.

The final conclusion we can make is therefore:

The "city beam" can be regarded as the most suitable (and perhaps as the only realistic) solution to the question of what type of

lighting should be considered optimum for the front of cars on lit roads. This is linked to the proviso that the road lighting should meet specific minimum requirements.

These conclusions are in agreement with those of the Commission Internationale de l'Eclairage (CIE, 1975a) and the Organisation for Economic Co-operation and Development (OECD, 1976c).

In the following chapter we shall deal with a number of consequences that might result from the introduction of a "city beam" of this type.

## 5. CONSEQUENCES OF INTRODUCING THE "CITY BEAM"

### 5.1. Introduction

The conclusions in para. 4.6. showed that the "city beam" was the most suitable compromise between "illuminating a lot" and "dazzling little". In the following section we shall discuss the consequences that arise following, or the questions that need to be answered before, the introduction of such a system. These aspects relate firstly to the car itself (costs, need for other lighting, variability), the traffic situation (combination with other lights, pedestrians, cyclists etc.) and the road (definition, analysis and specification of adequate road lighting).

### 5.2. The vehicle

1. Every change made to vehicles increases their cost. As far as the "city beam" is concerned, however, these costs depends very much on the system chosen. If a separate light is chosen - i.e. a real improved side light - the costs can be very low. An intensity of, say, 50 cd can be achieved easily using the techniques now applied generally in the car industry: in fact, almost all direction indicators and many of the brake lights of modern cars already have a similar intensity. For new models, therefore, this does not involve much increase in price, if any. Allowance should be made for some costs for converting existing models, particularly old cars. This should be taken into consideration when determining the duration of any transitional period.

If a "dimmed" low beam is chosen - which gives the advantages of a better standardisation of the dimensions and position and perhaps makes some contribution to illumination - somewhat higher costs may be expected, and certainly when this "dimming" has to take place automatically. Even here, though, the cost increase for new cars is not very drastic: the costs of the system proposed by the TRRL (Sabey, 1971) are estimated at some tens of guilders at

most. It should be remembered that the costs relate mainly to the automatic control. If an integrated system is being considered (Chapter 8), it might be possible for the same or a similar installation to be used for automation, which would mean that the costs would not be incurred solely by the "city beam".

The provisional conclusion therefore is that the introduction of a "city beam" would involve no major costs for the vehicles themselves. Depending on the system chosen, a few guilders to a few tens of guilders would be involved per car. However, see also point 2 below.

2. The "city beam" proposed here will, of course, occupy the same place as the present side light. In those cases where the present side light is also used as a parking light, it should be considered whether the "city beam" could likewise serve as a parking light. This may be undesirable because of the electrical power consumption of parked cars, particularly if the "city beam" has lamps with a bigger wattage. Moreover, the higher intensity of the "city beam" may be less suitable for parking lights, whilst it can be asked whether there should not be a clear distinction between moving and stationary (parked) cars. Lastly, allowance must be made for the fact that under some circumstances vehicles are parked "on the wrong side of the road" (two way roads with waiting restrictions on one side). A number of considerations are fulfilled by Noordzij & Van Kampen (1973), yet there is no question of any generally applicable solution (see also Mortimer & Post, 1972).

Another problem might arise because retroreflectors are less conspicuous in "city beams" as in ordinary low-beams. This may mean that the introduction of "city beams" ought to be linked with further restriction of parking without lights or with an increase of the requirements for retroreflectors.

For the time being it may be concluded that some further research is needed to find out whether a separate parking light is required or desirable in addition to the "city beam". Allowance will have to be made here for the relevant cost aspects.

3. Although it is not known exactly at the moment what margin is available for the "city beam", it is nevertheless clear that the spread of 4 cd to 60 cd as regards the intensity currently permitted for side lights by the ECE is too wide, especially when taking into account the fact that these values form part of a type inspection, i.e. the inspection of new - and often specially selected - lights under standardised conditions. There are only few data available on the variability that exists in practice between separate cars and also between the lights on one car.

### 5.3. The road and road-users

The most important and most far-reaching consequences of the introduction of the "city beam" is that the quality of road lighting will have to be maintained and often improved. We mentioned earlier (para. 4.1. and Appendix A3) that only when there is very little road lighting does the current low-beam headlight bring an improvement in the visibility of objects compared to the side light or the "city beam". This does not mean, though, that all road lighting above this level is automatically good; we merely observed that the situation is not improved by switching on low beams. Although additional research is desirable, it can be stated in the first instance that the first criterion (no improvement when low-beam headlights are switched on) is reached at about  $0.2 \text{ cd/m}^2$  (Knudsen, 1968) and the second criterion (the road lighting is good enough for the traffic situation) is reached at about  $2 \text{ cd/m}^2$  (NSVV, 1975; CIE, 1977b).

When only the requirements for road safety have to be met - thus disregarding matters of driving comfort - probably the luminance level can be lower ( $0,7$  to  $1,5 \text{ cd/m}^2$ ; see Schreuder, 1974a, NSVV, 1977). To make it clear that these luminance levels are still open to discussion, they will be referred to as level A and level B. It must be recognised that level A must be present on all roads used for traffic so as to enable the effective introduction of the "city beam" on all roads. For, if the luminance is higher than level A, the visibility of objects is not increased by

switching on low beams. It is thus not necessary to require that all roads should be provided with road lighting of at least level A before the "city beam" can be introduced. In fact, level A is not reached on all roads that have a traffic function; and this is certainly not the case if part of the road lighting has been switched off (as at present) because of the oil crisis. The slight gain that this can bring and the considerable drawbacks that may result have been described elsewhere (Blokpoel, 1974; Schreuder, 1974a; Tan, 1974; NSVV, 1974).

As we have said, level A is often not reached on roads with a traffic function; this of course applies even more to residential streets, which only have a slight traffic function. There are hardly any useful data on what fraction of the road network this involves, and even less data on the costs (in time, money and materials) that would be needed to ensure that all roads and streets inside built-up areas were provided with lighting that complied at least with level A. It may be anticipated that this involves a considerable part of the road network and that it would take a long time to bring the lighting to the required level once the relevant decision is taken. In any event, therefore, we must expect a lengthy period during which a considerable proportion of the roads will have lighting "lower" than level A. In principle, various measures can be taken in this situation:

1. Everything stays at it is. This is not to be preferred.
2. During the transitional period - i.e. before all road lighting has been modified - the use of low-beam headlights will be compulsory everywhere. The objections to this solution - either in a permanent or temporary form - are considerable, and have been explained above. It has been found that once low beams have been made compulsory there is often great opposition to the introduction of any improved light. Thus, when this measure is taken, it is imperative to stress its temporary character.
3. During the transitional period side lights are stipulated. This possibility merits serious consideration, though its drawbacks are obvious: firstly, many side lights are still too weak

to function optimally as signal lights and, secondly, many road lighting systems will still be inadequate during the transition. However, the advantage of this possibility is that it will enable a gradual transition to "city beam" situations.

4. During the transitional period side lights are permitted together with low-beam headlights. This offers every opportunity for the gradual introduction of the "city beam". There are several variations possible within this solution: firstly, it is left to the driver as to which lights he chooses. This has the advantage that there are no complications in the driver's function or in the equipment; the disadvantage is that side lights and low beams will be used together. As already stated, however, (para. 4.2.) this drawback weighs less heavily than formerly, whilst it is questionable whether any real drawback will still exist with the use of the "city beam". Secondly, the switching can be effected automatically (see para. 6.3.). Apart from the costs of this, the drawback is that it cannot be introduced immediately. Thirdly, an indication can be given for each road as to whether side lights (or "city beam") or low-beam headlights are compulsory. This requires a good criterion of what constitutes "good" road lighting, and good organisation particularly in cases where road lighting has only been partially improved; it also makes for more work for the driver and the police, and places much responsibility on the shoulders of the road authorities. And finally the decision can be kept to the driver, recommending the use of low-beam headlamps. The last possibility is thus obviously preferable.

If we consider the pros and cons of these variants, then the one mentioned first under 4. is clearly preferable, i.e. a situation that can be characterised as follows:

- road lighting is gradually raised to at least level A for all streets and roads;
- it is left to the drivers to decide whether to use side lights or low-beam headlights; the latter being recommended during the transition period;
- all cars are gradually fitted with "city beams".



N.B. 1. It should be considered whether the fitting of "city beams", particularly to new vehicles, should be linked to the installation of an automatic switching device, so that the second situation under 4. can gradually be achieved. This is of special significance if allowance is made for the fact that car signal lights form one unity (see also Chapter 8).

N.B. 2. It is preferable that "city beams" should be made compulsory once the transitional period is over, i.e. when all roads have reached at least level A. In view of the inevitable costs this will incur, allowance must be made for the fact that such a situation cannot be achieved, which means that possibility 4. must be regarded as a sort of final solution.

Also important for the road and road users are the consequences of the possible introduction of "city beams" on the visibility of retroreflectors on vehicles, on road signs and on road markings (see Appendix A3).

#### 5.4. Other road users and other conditions

1. Pedestrians and drivers have equal preference for the "city beam" (Fisher & Hall, 1970) at least in so far as the test-persons are car drivers. The results of trials using low-beam headlights seem to point towards a more general preference of pedestrians for low-beam headlights, despite the glare that they cause. Apparently, many pedestrians find that signalling the car's presence is more important than signalling other aspects. It is difficult to correlate this preference (which, by the way, was not ascertained reliably) with road safety. Moreover, the impression does exist that the pedestrians were greatly influenced by the fact that - particularly in the case of poor, obsolete street lighting - a single car with side lights was often more difficult to see amongst a number of cars with low beams. This is more a question of the mixed use of side lights and low-beam headlights and is more specifically attributable to the occurrence of a small

number of weak side lights amongst a large number of low-beam headlights. On the basis of these data, which are supported in part by accident statistics, it was concluded that combined use was undesirable (SWOV, 1969a). We have already stated above that this conclusion will probably be different for modern side lights, but more in particular for "city beams". It must also be remembered that the situation is not symmetrical, i.e. one car with low beams amongst many cars with side lights is less dangerous than a single car with side lights amongst many cars with low-beam headlights. This conclusion likewise seems warranted in view of the findings described in SWOV (1969a). However, it is questionable whether the conflicts have to do really with the conspicuity of the vehicles; it is found in many accidents that the pedestrians simply did not look (Kraay, 1975). Also social and psychological factors seem to play an important role (Kraay, 1975; Schreuder, 1977).

Another aspect involves the visibility of pedestrians, especially shortly before or during crossing. Crossing can often give rise to conflict situations or accidents (Kraay, 1974; SWOV, 1976a). Two cases can be differentiated: firstly, crossing takes place on a "zebra" (that is a pedestrian crossing where the pedestrian has priority) or, secondly, on some other section of the road. In the first case the (road) lighting at or near the zebra proves important, the main factors being the signalling of the zebra, the marking of the zebra and the possibilities of detecting the pedestrian on or near the zebra. The problems involved in the lighting of zebra - sometimes in the form of addition lighting - are described in detail in the literature (Schreuder, 1969a, 1965; Kraay, 1974; NSVV, 1967). The type of lights the cars are carrying is mainly of importance for the pedestrian's decision whether to cross or not, but less important for the visibility of the pedestrian himself. This latter aspect is especially important when pedestrians cross - more or less unexpectedly - at points where there are no zebras. Much research has been conducted into the relative hazards of crossing on or right next to zebras

(OECD, 1970), though no clear-cut conclusion has been reached. It may be anticipated, however, that in places where there are no zebras and the road lighting is of inferior quality, whether or not pedestrians will be detectable will depend primarily on the luminance contrast between them and their immediate background (De Boer, ed., 1967). These contrasts have already been discussed above (para. 4.1., Appendix A3). The conclusion reached was that if the "city beam" is used, the visibility of pedestrians can be boosted by the proper use of reflectorised material. However, as para. 5.3. showed, a clear contribution to the visibility can only be attained if use is made of reflectorised material of a high quality.

2. Nearly the same applied to cyclists, except that as a rule cyclists are moving in the same direction as car drivers and on the same side of the road. This means that usually only the rear of the cycle is visible. If the recommendations are adopted for the rear that were drawn up for country roads and when low-beam headlights are used (SWOV, 1973), then adequate visibility will be ensured when "city beams" are used on roads within built-up areas - i.e. where there are relatively low speeds and thus the required distance of detection is short.

The recommended reflective value is in fact  $450 \text{ cd/m}^2$  in order to ensure a detectability distance of 225 m for low-beam headlights. Inside built-up areas it can be stated that 80 m is sufficient for a speed of 16 m/s, a response time of 3 s and  $a = 4 \text{ m/s}$ , since the speeds are lower and there are more cyclists about. Thus, "city beams" will be sufficient (see also para. 4.1.). No allowance has been made here for the perhaps somewhat theoretical consideration that if road lighting is present - i.e. there is a higher adaptation luminance - the retroreflectors also need to have a higher luminance. Lastly, it is important that the characteristic "pedalling movement" of the cyclist can be used to boost the detectability of the cyclist as such by fitting retroreflectors to the pedals (SWOV, 1973; Roszbach, 1974; RAI, 1976). Further data regarding retroreflectors are given in Appendix A3.

3. One important question is whether it is desirable - for instance, via a difference in intensity or colour - to indicate the different categories of road users, say, to distinguish between cars on the one hand and cyclists and/or moped riders on the other. It has already been stated above that, in view of the available levels in coding dimensions, not too much should be expected of such distinctions. On the other hand we might ask firstly whether it is important to make such a distinction with a view to the anticipated manoeuvres and, secondly, whether there will be any consequences - legal or otherwise - of not indicating the different categories. At the moment little can be said on this subject; these problems, particularly in relation to slow-moving traffic, are being studied in more detail. The "city beam" is also being included in these studies.

4. A completely different problem is posed by day-time fog. Because of the higher ambient luminance, this requires very high luminance values for the signal lights. Roszbach (1974) mentions, quoting King & Finch (1969), that the luminance of the light sources must amount to at least 15 times the adaptation luminance. For a completely clear atmosphere this is of course far above the threshold value, but it is still not sufficient for dense fog. Here, too, further research is needed (see OECD, 1976a), but it is mostly claimed that at least low-beam headlights are required during day-time fog. In Chapter 8 we shall indicate how low-beam headlights (or fog lamps) can be incorporated within an integrated system of car signal lights.

5. Finally, we must take into account the new developments in city planning as show themselves in the "woonerf" concept. Here, one tries to unite the functions of living in residential areas with those of the mobility of the residents. The requirements for the public lighting - primarily for amenity, and only secondarily for transportation - are still under discussion. However, as regards car headlighting, it is recommended now already to avoid low beams (see Grootenhuis, 1976).

In conclusion it may be stated that, as regards the remaining aspects, the possible introduction of the "city beam" still requires some further research, though it seems at the moment that the consequences of such an introduction would certainly be acceptable.

#### 5.5. Conclusions from Chapter 4 and 5

The conclusions given in para. 4.6. and the considerations given in Chapter 5 can be summarised in a diagramme (see Table 1). For this diagramme the system of signalling functions, as given in para. 4.2. is used. Because research is still going on in this area, notably regarding the analysis of the driving task and the related transfer of information (Griep, 1972; Schreuder, 1974b) the diagramme should still be regarded as a provisional one.

The main aspects of the diagramme are the following: illumination - signalisation - glare. Furthermore, the diagramme will be restricted to the comparison of three crudely separated groups of lights, viz.: side lights - "city beams" - low-beam headlamps; without going into details as regards the different technical variations within these groups.

Also crudely it will be indicated in howfar lights from those groups may comply with the requirements as regards the application fields. This is indicated by + (good) 0 (poor) and - (bad). It will follow from the diagramme that for a number of signalling functions none of the three alternatives will comply. This means that for this, special signalling lights (brake light, direction indicator and the like) are needed.

N.B. The scheme is set up under the assumption of a fairly busy road with a public lighting installation of average quality.

## 6. TECHNICAL DESIGN

### 6.1. The traditional design of car lighting

#### 6.1.1. The headlamps

Although attempts have been made for many years to find an optimum compromise between much illumination and little glare, the results have always been substantially lower than those of good road lighting.

The main reason is that there is only a small angle between the light used to illuminate the road and any obstacles, and the light aimed directly at the eyes of any oncoming driver (see Figure 4). In Europe attempts are being made to reach this compromise by using a very sharp "cut-off" or "coupure" (the light/dark boundary). To do this the headlamps are constructed as follows: An incandescent coil-shaped filament is placed at the focus of a parabolic reflector. This produces an almost parallel light beam along the reflector axis. This is the high beam (Figure 5a). Also a second filament is fitted usually in front of the focal point in the same reflector, but on the reflector axis and parallel to it. This produces a ring-shaped beam of light (Figure 5b). A shield underneath the filament cuts off about half of this beam, so that the light when projected on a screen shows a shape like "half a pineapple ring". Suitable prisms fitted to the headlamp glass produce the familiar asymmetrical low-beam pattern (Figure 5c) (see also Rijnders, 1973).

The sharpness of the cut-off depends on the precision with which the separate elements have been manufactured; it is, of course, impossible to set too high requirements for a mass-produced article which must sell at a reasonable price. Extremely high requirements for the sharpness of the cut-off are not practicable, because considerable deviations from the required situation occur in practice because of dirt, the lens getting wet, incorrect setting, the loading of the car, or bumps or bends in the road (for this see para. 4.1. and the Appendices A3, A4 and A5).

Partly in view of these considerations, most Anglo/American countries opted for a different optical design of the low beam. An incandescent coil filament is placed cross-wise at the focus of a parabolic reflector. This produces a horizontal image on the road. This image is used to form the low beam by incorporating prism-shaped elements on the lamp glass.

A comparison of these two systems (European and American) reveals the following: the cut-off is considerably sharper in European lamps because the cutoff in this case is in fact an image of the edge of the dimming shield. In the American system the cut-off is formed by the edge of the image of the coil, which means it is less sharp. On the other hand the effective luminous flux is higher in the American "sealed beam" system. As a whole, therefore, the extra glare and extra illumination seem to compensate one another in the American system (De Boer & Vermeulen, 1951a, 1951b).

#### 6.1.2. The side light

Three basic constructions are currently used for side lights. The first is derived from the original "side light": a separate source of light comprising a bulb and a lens. Its location, shape, colour and intensity can be chosen within wide margins; consequently, there is a wide variation in both designs and regulations (see para. 4.3.).

The second construction is also much-used. Here a separate lamp is fitted within the headlamp reflector. The intensity may vary a great deal from one model to another; the shape and location are, however, governed by the regulations covering headlamps. Another difference from the first design is the brightness: because the entire headlamp radiates light in the second construction, the luminance is usually much lower than that of the mostly much smaller, separate side lights with the same luminous flux. This seems to be an advantage in the practical road-traffic situation (Fisher & Hall, 1974).

The third construction has been abandoned almost entirely. In this a separate bulb was fitted behind the lamp base of the twin-filament

lamp and this radiated light in a forward direction through a split in the lamp base. These constructions only enable very low intensities (approx. 0.1 cd or less). The three constructions are shown in diagram form in Figures 6a, 6b and 6c.

## 6.2. Optical aspects

There are two ways of creating a city beam with a luminous intensity of approx. 20 to 100 cd. Firstly, the luminous flux of the normal low-beam filament can be reduced (for instance by using a ballast resistance) so as to achieve the required intensity above the horizon. The reduction in intensity must go as far as 0.2, approximately. This requires a voltage drop from 12 to 7.5 Volt. The wattage is approximately halved, and the colour temperature drops considerably. The advantage of this system is that the standards as apply to low-beam headlights will also be retained for the "city beam". This holds true particular for the location and dimensions of the lamps. This benefit however is also obtained when the side-light bulb is fitted in the (low-beam) reflector (Figure 6b). As with low-beam headlights, the part of the road near the vehicle will remain illuminated. However, the corresponding part of the beam will also be reduced proportionately. A possible disadvantage is the restricted light emission in lateral directions. The second way of realising a "city beam" is to strengthen present side lights, for instance by increasing the wattage, and thus the luminous flux of the lamps. This is feasible using the constructions in Figures 6a and 6b and can usually be achieved very easily and without major modification for the Figure 6b construction; in the case of the Figure 6a construction allowance must be made for the increased heat given off by larger lamps, particularly if the lens of the existing side light is very small.

## 6.3. Switching aspects

As mentioned above (para. 5.3.), it may be expected that certainly in the first few years the road lighting on an important part of



the street network will be inadequate to allow the use of the "city beam". This means that low-beam headlights will have to be used on many streets. Thus, switching from low-beam headlights to side lights and vice versa will be needed. In principle there are two ways of doing this: switching by hand and automated switching.

Switching by hand is of course very simple. However, the driver has to make the decision to switch from one light to the other. The various possibilities (compulsory and free-choice) are discussed in para. 5.3. If manual switching is chosen and if the choice of lights is left to the driver or is made compulsory, then the driver's function is not made more difficult and there are hardly any cost-increasing factors.

Automatic switching has the advantage that the driver's task is facilitated compared to the present situation (at least in countries where the possibility of such a choice exists).

Sabey (1971) has described an automated system that meets the requirements. No details are given on the system's accuracy; since it is not switching on or off that is involved, but merely the gradual regulation of the lights, it may be expected that any divergence between the automatic devices in different cars will present no major problems. Nor are the costs indicated. Most probably they will amount to some tens of dutch guilders; if such an automatic device is used for an integrated system (see Chapter 8), then the costs will probably not present any major obstacle. The use of a pulsating direct current is more favourable as to power consumption than the use of a ballast resistance.

## 7. SUPPLEMENTARY RESEARCH

Supplementary research is needed into a number of points. This regards primarily a number of details; it should be pointed out, however, that neither the decision making nor the development research to be discussed further on need to be postponed.

### 7.1. Aspects research

1. A number of aspects have been indicated that require some further research. Thus, both the minimum value of the luminous intensity (ca. 20 cd) and its maximum value (ca. 100 cd) have been assessed a rather global way. Further research - particularly a study of the literature as quoted in Annex A7 - might give indication to some refinements. Further, it might be of interest to study in more detail the influence of the dimensions - and thus of the luminance - of the "city beams", more in particular in relation to the minimum value of the luminous intensity. However, because of the limited possibilities for technical implementation, the importance is restricted.

The permissible maximum of the luminous intensity (i.c. 100 cd) relates to requirements as regards the permissible glare level. The minimum (i.c. 20 cd) is required on ground of visibility. It is of importance - amongst others as regards the development research - to find out whether the margins of a factor 5 between minimum and maximum is adequate for practical implementation.

2. Little is known as yet about the desired beam pattern. Some regulations exist on the directions in which light should be emitted by the various light signals on cars; but little is known about the intensity values required in the various directions under different conditions of ambient luminance, partly because little can be said about the extent to which cars should be conspicuous and recognisable when viewed from different angles. This is linked to the fact that further research is needed into the relation between the characteristic movements of vehicles and the informa-

tion that is required (see Roszbach, 1972; 1974). Obviously, this has primarily to do with the sideways emission of light.

On the other hand we might ask whether the results of this research are needed for the "city beam". At present it is expected that a few simple observations, preferably in combination with the development research referred to in para. 7.2., will provide sufficient data to enable guidelines to be drawn up for "city beams". This expectation is based partly on the fact that a considerable margin between lights cannot be avoided (see point 1 above).

3. Further research is also needed into the "level A" that we mentioned above (para. 5.3.) as being the quality level of road lighting above which the additional use of low-beam headlights brings no improvement in the perceptibility of objects. Here again there are two possibilities: basic research should cover the criteria for selecting the relevant object and for its perceptibility and should also study how these criteria can be put into operation. Such research is being prepared within a wide context (CIE, 1975), but it will be a long time before results are available. The second possibility is to draw up an estimate of the said level, based partly on practical experience, partly on analytical considerations. At present the second possibility would seem preferable because it may of course be expected that aspects other than those involving lighting techniques will play an important role in the eventual policy decision (e.g. costs, power consumption, environmental nuisance, etc.). On the other hand the more basic research is interesting, because it may provide answers to other fundamental questions relating to road lighting, such as the value of level B (see para. 5.3.). It is of little concern, however, for the recommendation of a "city beam".

4. Lastly, it would be interesting to have more detailed information on acceptance by road users. Two problems can be differentiated here: firstly, how is the combined use of lights with differing luminous intensities (either different types of side lights, or side lights and low-beam headlights combined) evaluated

by the various categories of road users - also considering the fact that the intensity is not suitable for use as a primary coding mode. A role is played here in particular by the simultaneous presence of various vehicle types, especially if these have differing characteristic movements and/or differing legal status. The second problem involves the responses towards one another of various categories of road users. Here we are thinking especially of: motorists as drivers or as pedestrians, cyclists and moped riders, and also adults compared to children (and old people).

At the moment, however, it cannot be indicated exactly what data are actually needed at the moment or how these can be obtained. Since only a number of peripheral phenomena are expected to be involved (see, for instance, SWOV, 1969a; Fisher & Hall, 1970), it would seem sufficient to conduct some simple behavioural observations. Use can then be made of the experiences already gained with similar observations amongst pedestrians, especially those made under simulated traffic conditions (SWOV, 1969a; 1976a; OECD, 1976b).

## 7.2. Development research

It is clear from the above that most of the basic and practical problems linked to the possible introduction of the "city beam" have been solved, but that a number of problems of a more technical nature still remain. It may therefore be expected that, firstly, it will very soon be possible to state the functional requirements that a new "city beam" will have to meet and that, secondly, a some development research still needs to be done. We shall not deal in this report with the organisation of such a programme of development research, but we would comment that a considerable proportion of it can (and must) in all probability be undertaken by industry.

The most important part of the development research involves the production of a "workable prototype". By this we understand a

prototype of the possible ultimate design which has been sufficiently developed - also from a technical viewpoint - for it to be mass-produced over the short term if required. Therefore a review will have to be made not only of certain technical and constructional aspects, but also of production problems, aspects of factory mechanisation, economic aspects and cost question. Often it is necessary to manufacture not from one design, but from a number of alternative "workable prototypes". It is quite obvious that development research of this kind involves rather heavy expenditure, because all preparations (such as moulds) have to be made for some parts of the product - costly preparations which can only be recouped against any subsequent mass-production. It is therefore sensible to start such development research only if the entire "city beams" project stands a good chance of gaining eventual acceptance. At present, it seems that this is indeed the case, so this would justify a start being made on the development research.

Apart from matters of construction, production techniques and the possibilities of building the equipment into cars, the development research should concentrate primarily on questions of the temperature of side lights and their lenses, the "dimming" of halogen lamps, and making automatic devices operational for switching from low-beam headlights to side lights, and vice versa, in which consideration should also be given to the desirability of making that same device perform other switching functions as well.

Apart from these technical aspects, a number of aspects were mentioned earlier which could be studied as part of such development research - though, strictly speaking, they do not form part of it. Mainly these are aspects for which some sort of prototype is necessary or desirable in the trials.

The objectives of development research may be different. In some instances it is sufficient to demonstrate (e.g. by means of a laboratory design without actual development research) that the relevant problem can be solved in principle. If the technical feasibility of the problem is involved - and specifically in the

case of possible mass-production - then development research is required for the following reasons:

1. A prototype worked out in detail - also as regards the consequences of production and the costs - makes it possible for industry to draw up its policy plans.
2. A full-fledged prototype enables an evaluation to be made of the various aspects of introduction - which is of particular interest to those policy-making bodies concerned with international harmonisation, with standardisation, with the possibilities of certain producers gaining monopoly positions and with the interaction with other regulations.
3. On the basis of a full-fledged prototype the automotive industry can evaluate what the consequences will be for car production, a.o. for such aspects as "styling".
4. Sub-contractors and suppliers of semi-manufactures will be able to gear themselves to the situation.

### 7.3. Other aspects

#### 7.3.1. Separate parking lights

One aspect mentioned above is the possible need for a separate parking light system. As far as the power consumption is concerned, the investigation into a separate parking light could possibly be undertaken as part of the development research; of more importance is whether a parking light is needed and, if so, under what circumstances. The research work cited in para. 5.2. relates primarily to the rear of lorries and cannot thus be accorded general validity - and certainly not for "city beams" on the front of cars. Some further research is therefore desirable; however, the question is more: what should the relevant criteria be? Even without research it may be expected that - unless the law is changed in a number of countries - a parking light will remain necessary, at least under a number of circumstances. This brings us back again to the development research into the most suitable design for such a parking light, depending on the frequency of the (compulsory) use

and on the relevant requirements set for such use under the various conditions.

It should be kept in mind, however, that possible introduction of "city beams" may influence the possibilities for parking without lights (see para. 5.2.).

### 7.3.2. Use of side lights when low-beam headlights are in operation

At present most countries stipulate that side lights must remain lit when low-beam headlights are used. The argument for this regulation is that if one low-beam headlight cuts out because, say, filament failure, then there will at least be a side light left operating on that side of the car; thus the marking of the width of the car will be retained, at least in part. It should be considered whether this or a similar regulation should be retained (or introduced in those countries where it does not yet exist) when the "city beam" is introduced.

Three facets must be considered here:

1. A "city beam" normally uses more electrical power than a conventional side light, which means that the simultaneous use of low-beam headlights needs to be re-appraised.
2. Often a low-beam headlight fails because a fuse has blown in the car. It then depends on the wiring circuit as to whether or not the side light on the same side remains lit.
3. Alternatives exist, such as providing the front with reflectorised material (for instance, on the "fog visor" that is usually present just in front of the bulb in the headlamp). If a suitable material is chosen, it is possible to give the impression to on-coming traffic that both headlamps are lit. It is questionable, though, whether this should be precisely the information that is transmitted; if not, then perhaps even better alternatives could be found (e.g. retroreflecting license plates, see SWOV, 1969b).

### 7.3.3. Inspection requirements

Of great importance for the possible introduction of the "city beam" is the determination of the inspection requirements. At the moment,

type inspections are customary for elements of cars such as the lighting. Without going into the problems raised by type inspections themselves (Zaccharini, 1970a and b), there are a number of indications that there are quite considerable differences between the requirements for the type inspection and the values that actually exist in traffic particularly for car lighting (Yerrell, 1971a; Schreuder, 1971b; Thiry, 1974; De Brabander, 1972, 1974; Rumar, 1973a). In considering the introduction of "city beams", therefore, it is desirable to draw up inspection requirements that will not only meet certain criteria of type inspection, but will also provide a reasonable guarantee that the lights which are in fact already present on the roads will meet the relevant requirements to an adequate extent.

#### 7.3.4. Retroreflectors

In a number of sections we mentioned that, in view of current developments in the field of retroreflectors, it may be anticipated that the "city beam" can also contribute towards the visibility of objects fitted with reflectorised materials (Appendix A3). Two aspects are of importance: firstly, the possibilities of increasing the reflecting properties of road marking are limited (OECD, 1975) and secondly it should be considered that retro(re)reflectors which are easily visible with "city beams" may perhaps be too bright if low-beam headlights are used, and certainly if high beams are used. This relates specifically to the "legibility" of road signs and route indicators. It is therefore possible that for inside built-up areas - where the "city beam" will be used - other functional requirements will apply than for outside built-up areas, where low-beam headlights or high beams are used. Further research into this is needed; it may be expected, however, that this research can be based on current lighting know-how, which means that no extra experimental research will be needed (see e.g. Van Meeteren et al., 1968; CEMT, 1968; Schreuder, 1977). In so far as such supplementary experimental research is required, it will probably be simple to incorporate it within the more general research into



route monitoring as is being prepared as part of the general enquiry into the "analysis of the driver's task" (Griep, 1971).

#### 7.3.5. Vehicle lighting in reduced visibility; day-time lighting

Lastly, we come to the vehicle lighting requirements in poor visibility, both in the day-time and at night. Poor visibility relates firstly to the reduction in the visibility of the relevant road and traffic conditions due to the occurrence of atmospheric disturbances (fog, snow or rain, splashing water, flurries of snow, dust clouds) and secondly to conditions inside the car (dirty or steamed-up windscreens, dirty or wet headlamps, etc.). There is an interaction with other factors which may adversely affect traffic and road safety under meteorological conditions of this type, such as reduced skidding resistance of road surface, increasing specularly from road surfaces, icing, etc. Both the general aspects and those linked to signal lights are being studied at present (Anon, 1973a; Behrens & Kokoschka, 1973; Frederiksen, 1972; OECD, 1971, 1976a; Roszbach, 1972, 1974; Schreuder, 1964b).

As far as the possible introduction of the "city beam" is concerned, it is important to ask firstly whether a reason exists, in the case of poor visibility in day-time situations, for departing from the view that signal lights of medium power are important for road safety (Allen, 1970; Cantilli, 1969; King & Finch, 1969; OECD, 1976a; Roszbach, 1972; SWOV, 1974b) and for stating that very much stronger lights are required. On the basis of theoretical considerations it may be expected that this is the case and that the light intensity of, say, low-beam headlights or even high beams is more effective. (A summary is given in SWOV, 1975). This corresponds with current practical experiences. We shall return to this point in Chapter 8. It is questionable, however, whether low-beam headlamps during rain at day or during twilight are much to be preferred over "city beams" (Sweers, 1975; Schreuder, 1977).

Secondly, the question arises as to the most suitable signal lighting for poor visibility at night. Just like most questions about poor night-time visibility, this question cannot be answered

in general terms; the conditions of "ambient luminance", of visibility and of the traffic situation are much too divergent and too uncertain - to allow such an answer. In general it can be assumed, however, that in dense fog an intensity of a few hundred candela is desirable - obviously higher than is recommended for the "city beam". This figure is based on practical observations, in which the actual "meteorological visibility" was not always considered, no allowance was made for the simultaneous presence of many cars and where sufficient attention was not always paid to the fact that in present-day practice the only coding dimension used for the rear of cars is the intensity (and usually a low intensity signifies presence, and a high - or higher - one means that the brake pedal is being operated). As regards the rear of cars, research work is reported by Roszbach (1974). Other research (e.g. Mortimer, 1969, 1970, 1971) relates solely to a clear atmosphere. Hardly any research has been done for the front of cars, specifically into the correlation of signal light perceptibility and low-beam glare. Some relevant data can be found in Schreuder (1964b, 1977), though no solution is given (see also OECD, 1976a).

From this, the following conclusions can be drawn:

1. In poor visibility during the day (fog, rain, snow, etc.) headlamps are desirable, either on low or high beams.
2. At night when the weather is clear and when there is moderately poor visibility, "city beams" should ensure a sufficiently good effect as signal lights. In the case of really bad visibility a higher intensity is required, for instance that of low-beam headlights. At the moment it cannot be stated exactly at what meteorological visibility the change-over from "city beams" to low-beam headlights should be made.
3. On clear days the conspicuity seems to be better by using "city beams" or low-beam headlamps, although marker lights are not a clear necessity.
4. At day and during twilight with a clear atmosphere the "city beam" seems to be the best signalling light.

## 8. AN INTEGRATED SYSTEM FOR CAR LIGHTING

### 8.1. General

In this section we shall outline a car lighting system which can be regarded as an optimum solution to the various problems linked to the lighting of cars. The underlying principles of this system are as follows:

1. Signal lights, which can make the position (speed), changes in position and speed and planned changes therein, perceptible to other road users, are indispensable.
2. Such signal lights must be able to function in the day-time and at night, in a clear atmosphere and in poor visibility.
3. Under certain circumstances at night (viz. when there is no road lighting) the road and everything it may comprise must be made visible by means of lamps carried on the car.
4. The driver's task should be kept as simple as possible.
5. All this should be considered on the basis of the functional requirements set for traffic facilities in general, and for lighting in particular, viz. making it possible for the road user to reach his destination safely, quickly and comfortable, and at minimum cost (to himself and the community).

### 8.2. A universal system

A car lighting system which meets the above requirements might look as follows:

8.2.1. The following lights are carried by the car (all identical, left and right).

1. At the front:
  - polarised headlights (high beams)
  - "city beams"
  - parking lights
  - direction indicators (two levels)  
(possibly fog lamps).

2. At the rear:

- rear lights (two levels)
- brake lights (two levels)
- direction indicators (two levels)  
(possibly extra lights for pre-warning).

3. On the side:

- direction indicators (two levels)  
(possibly: position lights)

(These lights can be supplemented or, if necessary, even be replaced by retroreflectors).

4. This can be completed - as far as feasible - by special lamps, such as back-up lamps, search lights, cornering lamps, licence plate lights etc. These will not be considered in this report; it is sufficient to note that the use of those lights should be strictly reglemented in order to avoid mis-use and confusion.

8.2.2. To be used in the following situations:

1. Clear weather in day-time; bright sun

- front: polarised lights
- rear: high-level rear lights
- direction indicators front/rear and brake lights: high level.

2. Dusk, clear weather

- front: polarised lights
- rear: low-level rear lights
- direction indicators front/rear and brake lights: low level.

3. Night-time, clear weather, with road lighting (no one-way traffic or the like)

- front: "city beams"
- rear: low-level rear lights
- direction indicators front/rear and brake lights: low level.

4. Night-time, clear weather, no road lighting

- front: polarised lights
- rear: low-level rear lights
- direction indicators front/rear and brake lights: low level.

5. Day-time and dusk, poor visibility (fog)

- front: polarised lights (possibly also fog lamps)

- rear: high-level rear light
  - direction indicators front/rear, brake lights: high level.
6. Night-time, poor visibility (fog; with or without road lighting)
- front: polarised lights
  - rear: high-level rear lights
  - directions indicators front/rear, brake lights: high level.

A simplified system is described by Schreuder (1977). See also Tabel 2.

### 8.3. Some additional remarks

1. A few technical and legal problems still need to be solved before polarised light can be generally applied (see OECD, 1976b). As suggested above, it has been assumed that the driver may decide for himself whether or not he wants to use his "analyser".
2. The effect of extra fog lamps at the front is very doubtful in its value (Schreuder, 1971b; SWOV, 1975). In any event their colour is of no significance (SWOV, 1975).
3. The colour, position and intensity of the "high-level" rear lights should be adequate for the day-time situation with or without fog, and also for the night-time situation with fog. This light thus replaces the present "rear fog lamp". Here, we have assumed that the required levels for "day-clear", "day-fog" overlap sufficiently to allow the use of just one light. If not, then a three-level switching is necessary. This third level is in operation for "day-fog". When such a third level is taken into account, the systems proposed in para. 8.2.1. and by Roszbach (1974) respectively are completely in accordance. Roszbach even indicate the possibility of a fourth level. Furthermore, it should be noted that a third level not only pertains to the rear lights, but also to the direction indicators and the brake lights.
4. The driver should have as little switching as possible to do. Firstly, switching complicates his task as a driver and, secondly, it introduces the risk of faulty decisions. It is therefore highly desirable that the entire system should be controlled by just one

automatic device. As regards the situations outlined in para. 8.2. this can be realised without difficulty; the only thing needed is that at a number of ambient luminance levels which have to be determined more precisely, a switch-over must be made from one specific level to another. This can, of course, be done gradually. According to the proposal put forward here (though this is of course merely an outline and is open to further discussion), the lighting at the front must be switched on at a different level than that at the rear. Of course, this will provide no problems technically.

A similar system can be used for situations 5 and 6; the wiring circuits, however, are different from the preceding cases in that 5 and 6 are identical to 1. Here, two solutions can be chosen: either the driver switches on the "fog" system so that the overall system remains fixed in the no. 1 situation or this "fog" system is switched on by an impulse from the road-side fog-warning system. The second solution is, of course, only suitable for partial application at the most.

When a third level is introduced, during the operation of the "fog" system, switching is needed from the very high level at day to the high level at night. This can be performed by the same automatic device, be it at another level of the ambient luminance.

## 9. CONCLUSIONS

1. The report shows that the contribution of low-beam headlamps in lighted streets for the illumination and thus for the visibility of objects is small and usually can be neglected. Furthermore, the optimum conditions of observation are reduced by the glare of low beams.
2. The present side lights usually are too weak for marker lights, although recently there is a clear improvement.
3. The optimum light for the front of motor vehicles to be used on streets with public lighting should have a luminous intensity lower than the present low-beam headlamps, but higher than the present side lights. The luminous intensity must be at least 20 cd and not more than 100 cd.
4. A "city beam" of this type can give a considerable contribution to the visibility of reflectorised objects. The visibility of non-reflectorised objects must be ensured by adequate public (overhead) lighting.
5. The following description gives the optimum way to realise the "city beam" concept:
  - A. The present low beams are reduced in luminous intensity. Here, the best way is to reduce the luminous flux of the low-beam lamps. The luminous intensity should be between 20 cd and 100 cd;
  - B. The transition from low beam to "city beam" is made by manual switching;
  - C. A further future improvement can be found by automatic and gradual "dimming", more in particular if the automatic device can be used for the switching of other lights, e.g. the rear lights of the vehicle;
  - D. When the (obligatory) use of low-beam headlamps is selected for the transition period, the temporary character of this measure should be stressed.
6. The introduction of the "town beam" will reduce many of the difficulties of to-day's night-time driving. It is to be expected that the additional costs will be marginal, both for the individual car driver and for the public authorities.

At present there are no alternatives to improve the night-time situation. The introduction of the "city beam" concept is compatible with those systems to improve the night-time traffic, which seems to be applicable in the future.



	side lights	"city beams"	low beams
<u>illumination</u>			
- road, run of the road	-	-	- to 0
- objects	-	-	- to 0
- retroreflectors	-	0	+
<u>signalling</u>			
- presence	0	+	+
- contour, type of vehicle	-	-	-
- distance	0	+	0
- speed, direction	0	+	- to 0
- changes in speed, direction	-	0	- to 0
- planned changes	-	-	-
<u>glare reduction</u>	+	+	-

Table 1.

---

Signalling light front	: low : 20-100 cd medium: >2000 cd (low beam high : >50.000 cd (high beam)
Signalling light rear	: low : 5-25 cd medium: 20-100 cd high : 200-1000 cd (fog rear lamps)
Direction indicators, brake lights:	low : 20-100 cd medium: 200-1000 cd high *: 200-1000 cd

---

\* over 2000 cd is not feasible

---

Surround illuminance	weather	
	clear	fog
E < 10 lux	L*	M
10 < E < 100 lux	L	M
100 < E < 1000 lux	M	M
E > 1000 lux	H	H

---

\* add: low beams for illumination

---

Driver selects: "clear weather" / "fog"

"clear weather"

starting point E = 0	: all L; low beams operational
at E = 10 lux	: low beams extinguished
at E = 100 lux	: from L to M
at E = 1000 lux	: from M to H

"fog"

starting point E = 0	: all M
at E = 1000 lux	: from M to H

---

Table 2.

FIGURES 1 - 6

Figure 1. The cumulative frequency distribution (p in %) of the reflection factor of clothing (after Knudsen, 1968).

Figure 2. The road surface on a considerable distance is an important part of the back-ground for obstacles. The arrows at 60 and 160 indicate points 60 m resp. 160 m ahead of the place from where the picture was taken.

Figure 3. Road surfaces, also when dry, exhibit specular reflection (Photograph Stichting Prometheus, Amsterdam).

Figure 4. The geometry, relevant for vehicle lighting.

Figure 5. The principle of headlighting: high beams (a) and European "E" low-beam headlights (b and c).

Figure 6. Three forms of realisation of side lights. D: "duplo" headlamp S: bulb for side light (after Schreuder, 1966).

Figure 1

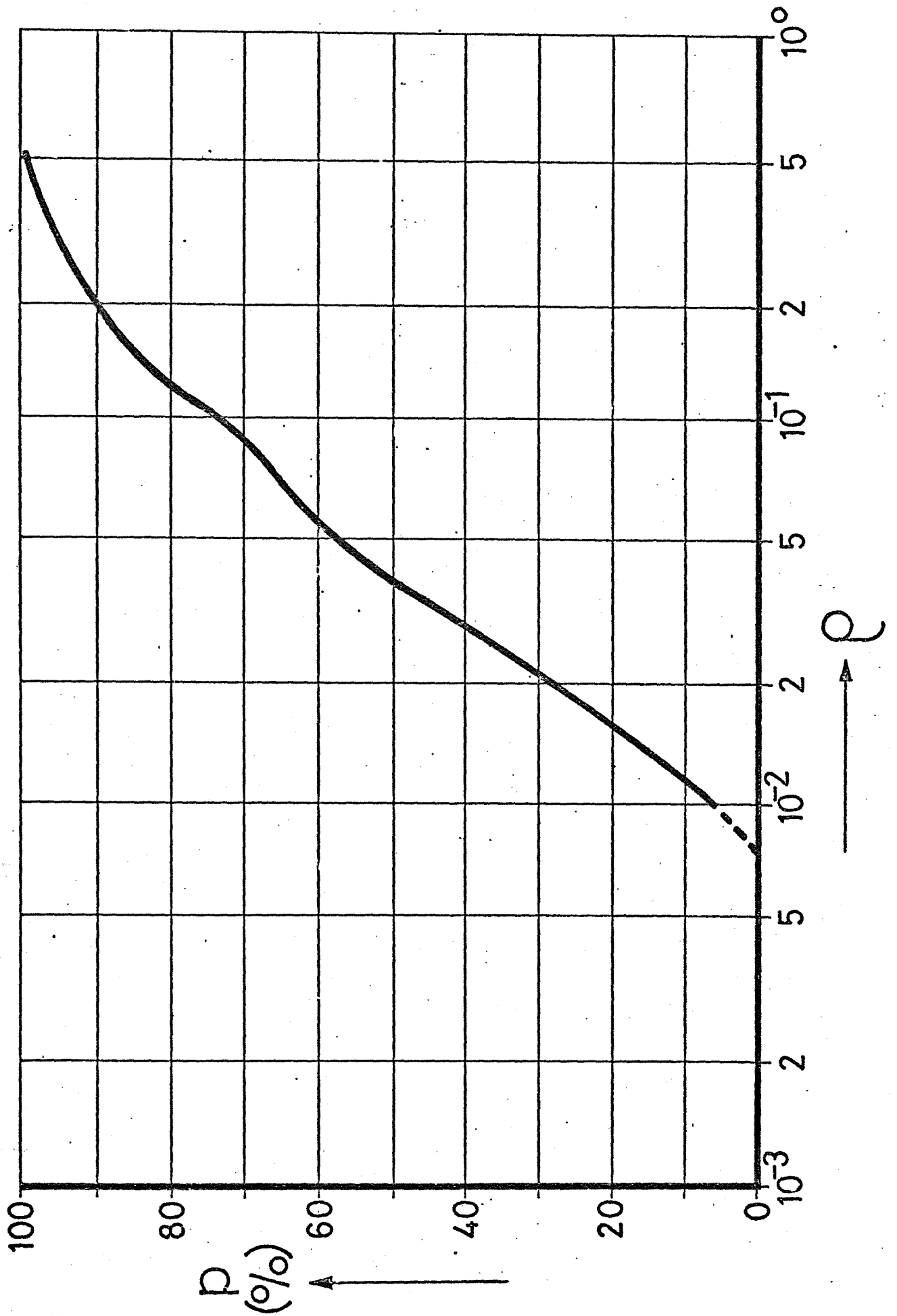


Figure 2

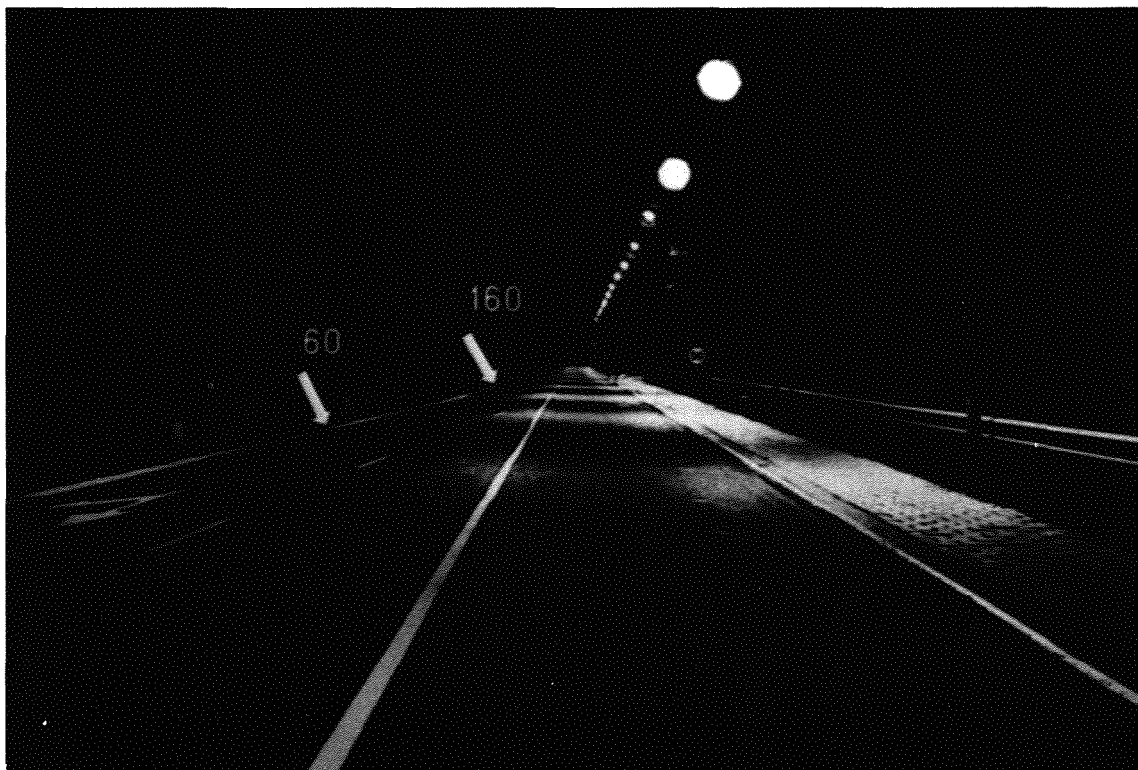
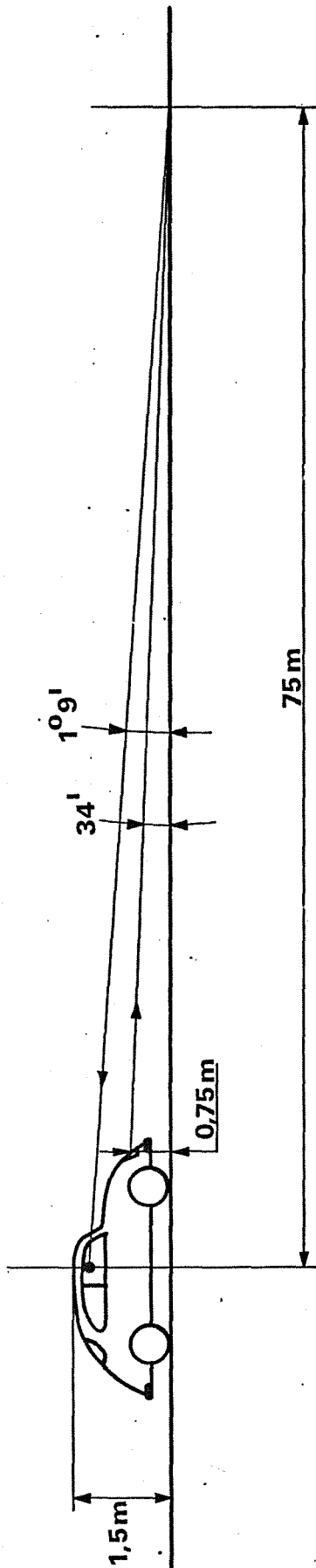
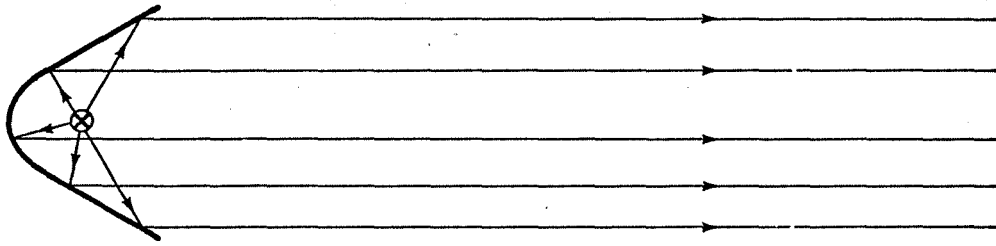


Figure 3

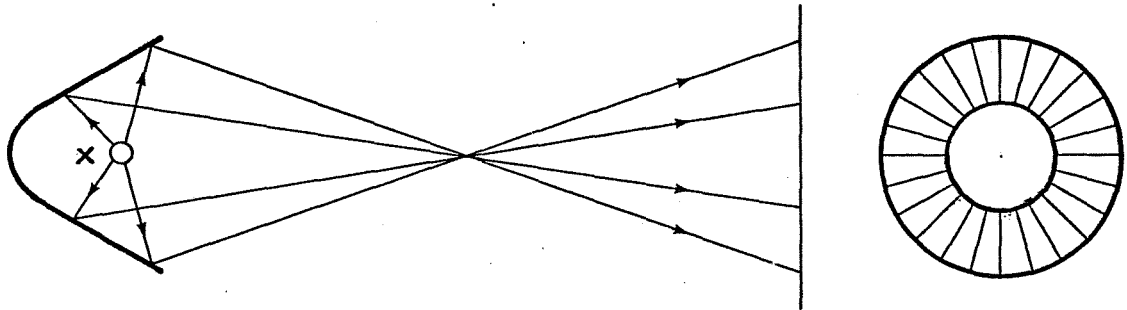




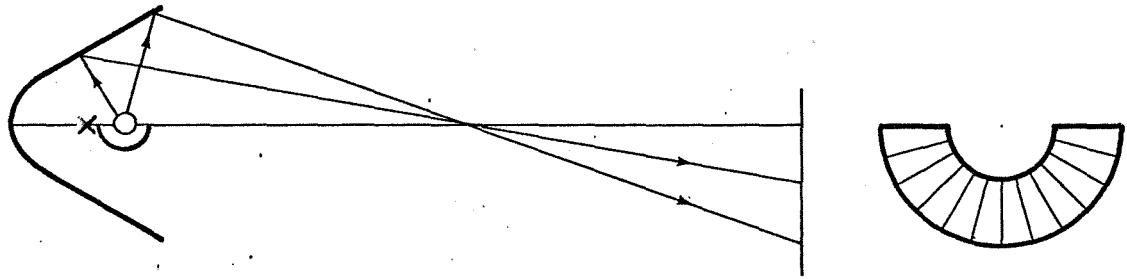
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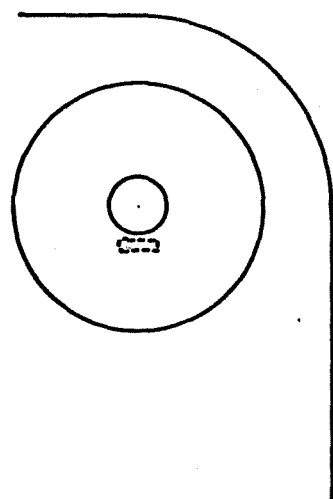
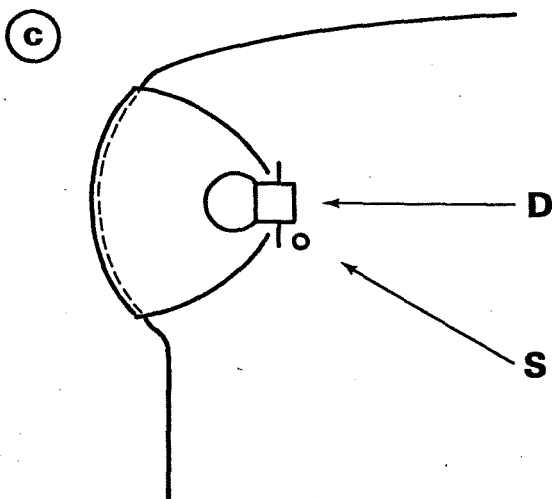
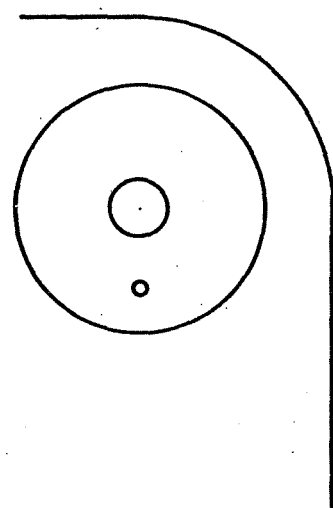
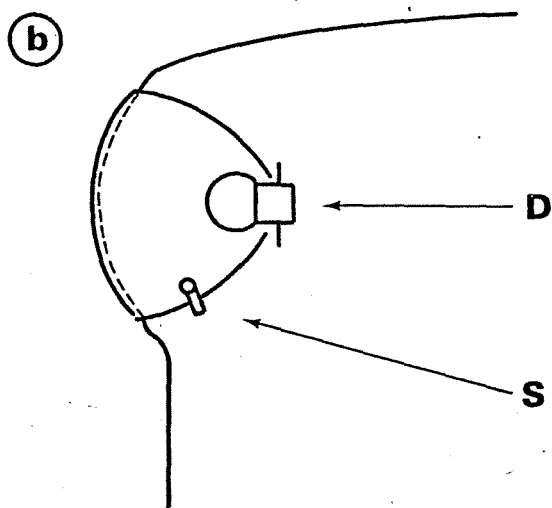
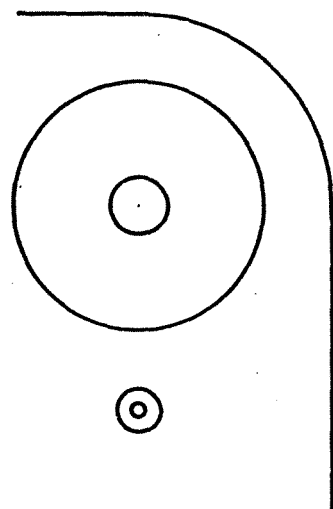
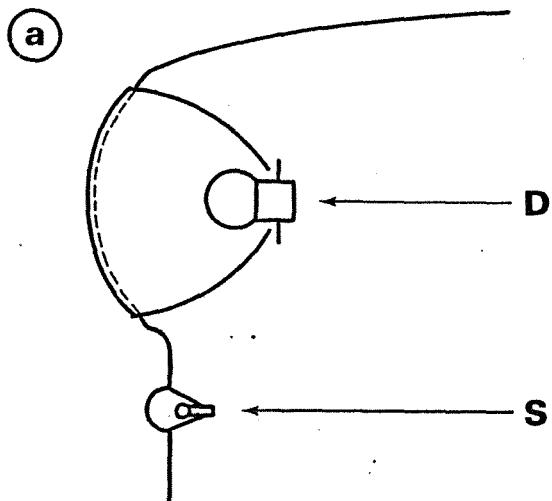


b



c







APPENDICES A1 - A7

Appendix A1. Accidents.

Appendix A2. The use of low-beam headlights.

Appendix A3. Contribution to illumination, retroreflectors.

Appendix A4. Glare.

Appendix A5. Dirt; aiming of headlights.

Appendix A6. Improvements to low-beam headlights.

Appendix A7.

APPENDIX A1. ACCIDENTS

The first large-scale enquiry into the effect of the use of side lights or dimmed headlights on road accidents was undertaken in the U.K, and is described by the (Transport and) Road Research Laboratory (RRL, 1964). It is stated in the summary that "the only significant change found which can be associated with the use of dipped headlights was the reduction in pedestrian accidents on less well-lit roads in Bristol".

The Institute for Road Safety Research SWOV has conducted a similar investigation in The Netherlands (see SWOV, 1969a). In this case the conclusion on road accidents was: "the increase from about 35% to about 85% low-beam headlight drivers ... had no demonstrable effect on the total number of traffic accidents". It may be concluded, though, that relatively more pedestrian accidents took place involving cars carrying side lights.

In addition the accident pattern was studied in Belgium after the use of low-beam headlights had been made compulsory there on 15th June 1968 (De Brabander, 1971). The final conclusion was that, even if allowance was made for the fact that checks on the use and setting of low-beam headlights were better in Belgium than in many of its neighbouring countries, low-beam headlights were still just as unsuitable as side lights for use on lit roads: no significant changes in the accident pattern were found which could be attributed directly to the type of vehicle lighting.

The Working Part 20 of the ECE held an enquiry amongst the member states. The answers from nine countries show that no data exist elsewhere which could provide an answer to the said question.

APPENDIX A2. THE USE OF LOW-BEAM HEADLIGHTS

The investigations in the U.K, and in The Netherlands both showed that if drivers are offered the choice between side lights and low-beam headlights, they will prefer low-beam headlights on poorly lit roads. Obviously, a link exists between the quality of the road lighting and the choice of car lighting: however, nothing further is known about this correlation.

In a number of countries it is left to the driver as to whether he uses side lights or low-beam headlights inside the built-up area on lit roads. Since the relevant criteria may differ, it may be expected that in many instances some cars will carry side lights and other low-beam headlights. The ECE enquiry shows that only the above reports of SWOV and RRL contain data on the actual "combination ratio" that occurs. Since a change in this combination ratio has no influence on the accident rate, it was concluded in both reports that it was the combined occurrence of the two types of car lighting that led to hazardous situations rather than the actual ratio. It must be remarked that in both investigations many weak versions were still found to exist amongst the side lights. It is therefore doubtful whether such a strong emphasis should still be placed on the need for all cars to carry similar-type lights. Figure A2-1 shows a number of recent measurements of side lights. The frequency relates to the number of types offered for inspection, and not to the frequency of their occurrence on the roads. Of particular interest is the median value: between 11 and 12 cd.

APPENDIX A3. CONTRIBUTION TO ILLUMINATION, RETROFLECTORS

The contribution of low-beam headlights to the illumination of the road and of any objects on it is slight. For the rest, little research has been devoted to the visibility, specifically when low-beam headlights alone are used. The reason is that low-beam headlights are mainly used when oncoming traffic is present. Visibility measurings are thus mainly restricted to the two following cases: headlights (not important here) and low-beam headlights with oncoming traffic (see also Appendix A4). As has already been indicated, this lighting system usually means that the objects show light against a dark background. Road lighting on the other hand mostly results in a reversed silhouette effect. If both types of lighting are present at the same time, the two effects may be expected to counteract one another, thus reducing the visibility. The calculation given in SWOV (1969a, p. 20 ff.) lead to the verdict that "on roads with an average road-surface luminance greater than about 0,1 cd/m<sup>2</sup> (i.e. on all roads except really badly-lighted ones) the contrasts of objects on the road will not be as great with low-beam headlights as with side lights". It was added that low-beam headlights certainly bring an improvement for very short distances and on roads where there are very dark patches (caused by rain, for instance). These conclusions correspond with the findings of Knudsen (1968), Dunbar (1938), Fisher (1968), Smith (1938) and Waldram (1938).

The use of low-beam headlights does, however, bring a clear increase in the visibility of retroreflectors. In SWOV (1969b) it is stated that under a number of specified provisos

$$E_o = \frac{r \cdot I \cdot O}{R^4}$$

where  $E_o$  is the threshold value of the signal lights,  $I$  the luminous intensity of the lamps,  $r$  the reflecting power,  $O$  the surface of the reflector and  $R$  the visibility distance. ( $E_o$  in lux,  $I$  in cd,  $r$  in cd/m<sup>2</sup> per lux,  $O$  in m<sup>2</sup> and  $R$  in m).

The luminance of the retroreflector is proportional to  $I$  (if  $E_0$ ,  $r$  and  $R$  are constant). A change-over from present side lights ( $I < 50$  cd) to low-beam headlights ( $I > 1000$  cd, from both lamps together in each case) will therefore bring a great increase in luminance. The influence of the visibility distance (which is more importance for road safety than the luminance) is, however, much slighter, because  $R$  is proportional to  $\sqrt[4]{I}$ . So if  $I$  becomes 20 times bigger,  $R$  only increases by a factor of  $\sqrt[4]{20} = 2.1$ . If we now consider the "city beams", which are discussed in the report and which have a luminous intensity of, say, 100 cd each, then the difference in visibility between these "city beams" and low-beam headlights becomes even smaller, viz.  $\sqrt[4]{5} = 1.49$ . Provisional observations confirm this: it seems that lights with an intensity of approx. 100 cd can also contribute towards the visibility of retroreflectors.

The theory and the fields of application of retroreflectors and reflecting materials have been treated in e.g. James & Hayward (1960) and Anon (1958).

APPENDIX A4. GLARE

Glare is caused when one or more bright light sources are present within the field of vision. This may make it more difficult or even impossible to perceive any objects ("real" glare, or "disability glare"). Also the ease of perception may be affected ("discomfort glare"). It is generally assumed that low-beam headlights cause a considerable degree of discomfort glare, and that in this respect side lights are much more preferable, particularly when pedestrians or cyclists are involved. There is still a great difference of opinion as to whether or not the degree of disability glare caused by low-beam headlights can be tolerated. We shall summarise the results of some studies into this below.

In SWOV (1969a) it was concluded that  $\bar{L} = 3.38 n/d^2$ , where  $\bar{L}$  is the minimum road-surface luminance required,  $n$  the total number of oncoming cars visible at the same time, and  $d$  the lateral distance between the rows of encountering cars. This correlation is valid under the following conditions:

- a. only one lamp per car is visible;
- b. this lamp is a correctly adjusted "E"-type low-beam headlight;
- c. a threshold value of 20% in contrast sensitivity is accepted;
- d. fairly small objects are being observed.

For  $n = 3$  and  $d = 3$  m (neither of which are extreme values) it follows that  $\bar{L} = 1$  cd/m<sup>2</sup>. This means that average road-surface luminance should be 1 cd/m<sup>2</sup> (the value recommended by the Nederlandse Stichting voor Verlichtingskunde for not too busy urban streets; NSVV (1975) so as to prevent the contrast sensitivity from decreasing by more than 20% - and this on a fairly wide road with only three oncoming cars. These considerations led to the following conclusions (SWOV, 1969a, p. 30):

"Even the present internationally standardised asymmetrical European low-beam headlight causes an unacceptable degree of glare for oncoming traffic, unless there are only a few oncoming vehicles, or the average road-surface luminance is much greater than at present customary, or unless the central reservation for

dual carriage-way roads is very wide. No such conditions are customary in built-up areas, and present low-beam headlights are therefore inadmissible in built-up areas because of the glare they cause.

Note: The newly developed duplo-halogen lamps cast about the same light at oncoming traffic. As regards glare, therefore, they hardly differ from conventional lamps, also having regard to the little they contribute to road-surface luminance."

The literature summary given by Judd (1969) comes to a similar conclusion, and so do the results given by Bindels (1970).

APPENDIX A5. DIRT; AIMING OF HEADLIGHTS

1. Dirt

If a low-beam headlight is dirty on the outside, two effects occur. Firstly, part of the light is absorbed by the dirt, thus reducing the effective luminous intensity. Rumar (1973a) has shown that this absorption amounts to as much as 10-20% on what appears to be a clean lamp. On muddy roads the absorption is almost always above 50%. One remarkable finding is that most drivers hardly notice an absorption of 60%, if at all. All this can, of course, lead to a considerable reduction in the visibility (see also Cox, 1968). A second effect is the increase in glare. From (unpublished) research in The Netherlands it has been found that during rain the light intensity of low-beam headlights in the direction where glare is likely to be caused is on average one and a half times higher than the comparable intensity in dry weather. In addition to this comes the glare that may result from reflections on the (wet) road surface. Dirt on the other hand has a greater influence: glare may increase threefold as compared with a clean, dry glass.

2. The aiming of low-beam headlights

The function of low-beam headlights is based on a compromise between illumination on the one hand and glare on the other. This compromise is always characterised by a very steep gradient in the luminous intensity near to the horizontal (known as the "cut-off"). The principle is that, seen from the lamps, the eyes of the oncoming car drivers are always above the horizon, and the part of the road to be lit is below. If there is a sharp cut-off, the glare caused to oncoming traffic can be low and at the same time the road illumination high. However, in view of the values of the angles involved here, it is clear that the technical possibilities for mass-production are limited.

Figure A5.1. indicates how the gradient has developed over the years to the ratio  $E_{50}/E_H$ . These factors are proportional to the luminous intensities in a direction which corresponds to a point 50 metres



ahead of the car and in a horizontal direction. Between these two directions there is an angle of only approx. 40 minutes of arc. Figure A5.2. shows the ratios that would be needed to achieve further improvements.

There are, however, a number of practical restrictions on the use of very sharp cut-offs in traffic. These are: faulty adjustment in the car, changes in position as a result of the loading of the car, and the influence of bumps in the road.

The correct adjustment for car headlights is no simple matter because of the accuracy involved. Even during voluntary inspections, in which we may expect to meet mostly those people who take the maintenance of their car seriously, it has been found that as a rule more than one-third of all headlamps are incorrectly set (SWOV, 1969a). Figure A5.3. shows data taken from Lindae (1969). Even with an extraordinary wide range of acceptance (with a permissible variation of 20 cm at 10 m distance) almost half the vehicles still prove to have a faulty headlamp setting. Figure A5.4. shows some British data (Glover, 1963) in the form of a cumulative frequency distribution. Here, too, it can be seen that a very wide spread in setting exists. Hardly any improvement can be expected as long as the accuracy of the setting has to be checked by looking at the position of the cut-off on a screen. A mechanical aiming system, however, does not seem to be more accurate, although it is simpler to use (Hemion, et al., 1972).

A second major restriction on the effectiveness of low-beam headlights as a means for road illumination is to be found in the deviation in the position of the beam away from the horizontal, as occurs because of variations in the car's state of loading. An investigation into this has been made in the U.K. (Hignett, 1970). In this it was found that about 1/3 of the vehicles had headlights that were aimed half a degree too high, a deviation which already brings a clear increase in glare. The findings are shown in Figure A5.5. Even whether or not the petrol tank is

full may have a considerable influence, as may be seen in Figure A5.6., quoted from an example given by Walker (1972). It is worthy of note that the driver and the passengers in this case had comparatively little influence for the vehicle in question.

In all these consideration on headlamp settings it has been assumed that there is an unequivocal system of measuring the aim and the deviations in it. But this, too, is far from being the case; Zaccharini (1970b) found that, of a group of 32 headlight aiming devices, the average vertical deviation was  $0.08^{\circ}$  downwards, with a standard deviation of  $0.17^{\circ}$ . This means therefore that 1 in 20 units may be expected to have a standard value that is more than  $0.4^{\circ}$  too low or almost  $0.3^{\circ}$  too high. Similar findings were recorded for the horizontal setting.

The conclusion given by Walker (1972) is that visual aiming on a screen is the least accurate of all systems and that only mechanical aiming is suitable for maintenance purposes. This conclusion is linked to the beam patterns customary in the USA which give a less sharp cut-off than the normal European patterns. Consequently, his findings cannot be applied as they stand to the European situation. It has been proved, however, that even mechanical aiming can still result in substantial errors. The inaccuracy in a vertical direction may amount to as much as  $0.2^{\circ}$  (which Walker describes as "excellent"). It has been assumed here that the lamps have no tolerance between one another. Of the total of 300 batches of headlamps tested, only 13 met all the requirements! In many cases the glare was found to be too high. The average glare value (EB 50) of these 300 headlamps was 0.301 lux at 25 m with a standard deviation of 0.038. The maximum permitted value is 0.3 lux at 25 m. The conclusion Zaccharini drew from these measurements was: "the question arises whether such a bad compliance must be tolerated in order to account for the tolerances required by the headlight manufacturing process. If this is the case, it is obvious that the values specified in European Light Regulation 1 are unrealistic and must thus be revised in order to adapt them to the factual possibilities of today's production techniques".

This last statement, however, is in itself again questionable. One could envisage that manufacturing procedures will be adapted to the requirements put forward by the traffic.

One last important point is the outcome of a number of measurements made in normal traffic. Under normal traffic conditions the luminous intensity was measured from the headlamps of passing cars in the direction of the eyes of oncoming car drivers. Under the auspices of the Transport and Road Research Laboratory, U.K., measurements of this kind were made in the U.K., Belgium, The Netherlands, West-Germany and France (Yerrell, 1971a). Some of the results are given in Figure A5.7., which shows that in normal traffic (but excluding unevennesses in the road, which were deliberately disregarded) about 80% of the cars cause more glare than is legally permitted; under the conditions selected here the legal limit is set at 375 cd for both lamps together, which is twice the "EB 50" value. Measurements of this kind were also made by an institute in The Netherlands, though the results are unpublished as yet. The findings are, however, similar to those of Yerrell.

APPENDIX A6. IMPROVEMENTS TO LOW-BEAM HEADLIGHTS

From the above it can be concluded that low-beam headlights in their present version are not suitable as vehicle lighting on lighted roads. The relevant conclusion from SWOV (1969a) is quoted in para. 4.1.5. Proposals have been made from various quarters for achieving an improvement. The use of halogen lamps yields a gain in the luminous flux; no advantage can be anticipated in this direction, though, as the requirements relating to glare have remained about the same. Although theoretically some gain in visibility should be expected (De Boer & Schreuder, 1969), visibility measurements give no evidence of this (Rumar, 1970). Nor do other variations in beam pattern appear to yield any gain; in particular, no improvements will be achieved by changing over to a less sharp cut-off, i.e. one which is less susceptible to incorrect setting. This is shown by a number of other studies in which European symmetrical low-beam headlights and the U.S. "sealed beam" system were compared (on this subject see, for instance, De Boer & Vermeulen, 1951; GTB, 1955). The advantage that Rumar (1973b) found with the sealed beam was attributable more to the characteristics of the experimental situation than to a favourable effect of the less sharp cut-off.

Another possibility of obviating a number of the negative properties of low-beam headlights is to stabilise the lamp, or the entire car (see, for instance, Moore & Christie, 1970; Devaux, 1970; Cibié, 1970; Yerrell, 1971b).

APPENDIX A7.

The upper limit of the luminous intensity of the "city beam" is conditioned by the level of admissible glare. A number of relevant research results are given by:

Adrian (1969, 1964, 1969); Allen (1970); Bindels (1973); De Boer & Morass (1956); Fisher (1974); Fisher & Christie (1965); Hartmann (1963); Hartmann & Moser (1968); Hemion (1968); Johansson et al. (1963); Johansson & Rumar (1968); Vos (1963); Webster & Yeatman (1968); Wortman & Webster (1968).

The lower limit of this kind of "city beam" has to be set up, based on considerations of visibility (conspicuity). Some relevant data are given by: Balder (1956); Boissin & Pagès (1963); De Brabander (1972); Fisher (1974); Hargroves (1971); Judd (1969); Projector et al. (1969); Roszbach (1974); SWOV (1969, 1973).

Some data regarding the relationship between conspicuity and dimensions of signalling lights are given by (or summarised by): Adrian & Eberbach (1967); Hartmann & Ucke (1972); Middleton (1952); Schreuder (1973).

FIGURES APPENDICES A1 - A7

Figure A2.1. The luminous intensity  $I$  in cd of a number of recent types of side lights ( $n = 55$ ; median between 11 and 12 cd).

Figure A5.1. The development of the cut-off of low-beam headlamps E: European low-beam SB: Sealed Beam (after Devaux, 1970).

Figure A5.2. Hypothetical luminous intensity distribution of low-beam headlamps. Above the horizon along the path of the eye of oncoming drivers, below the horizontal along the right hand kerb-line (right hand driving). Above the horizon maximum admissible intensity ( $E_H = 0,7$  lux - point 7 -  $E_{B50} = 0,3$  lux on 25 m). Curve 1: normal low-beam. Curves 2 and 3 with an increase of 50% and 100%. Curves 4, 5 and 6 correspond with a visibility distance of 100 m, 110 m and 120 m respectively (after De Boer & Schreuder, 1966).

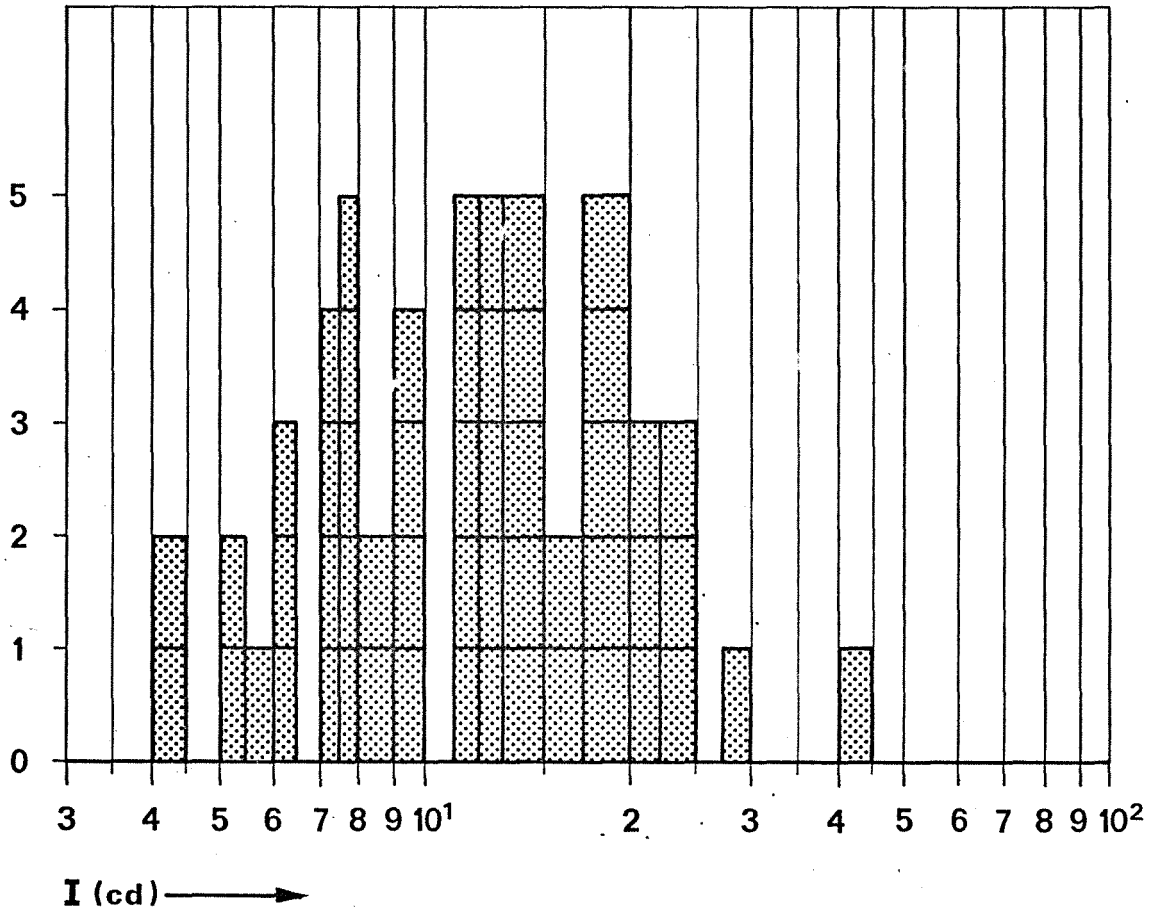
Figure A5.3. Frequency distribution of headlamp setting (after Lindae, 1969).

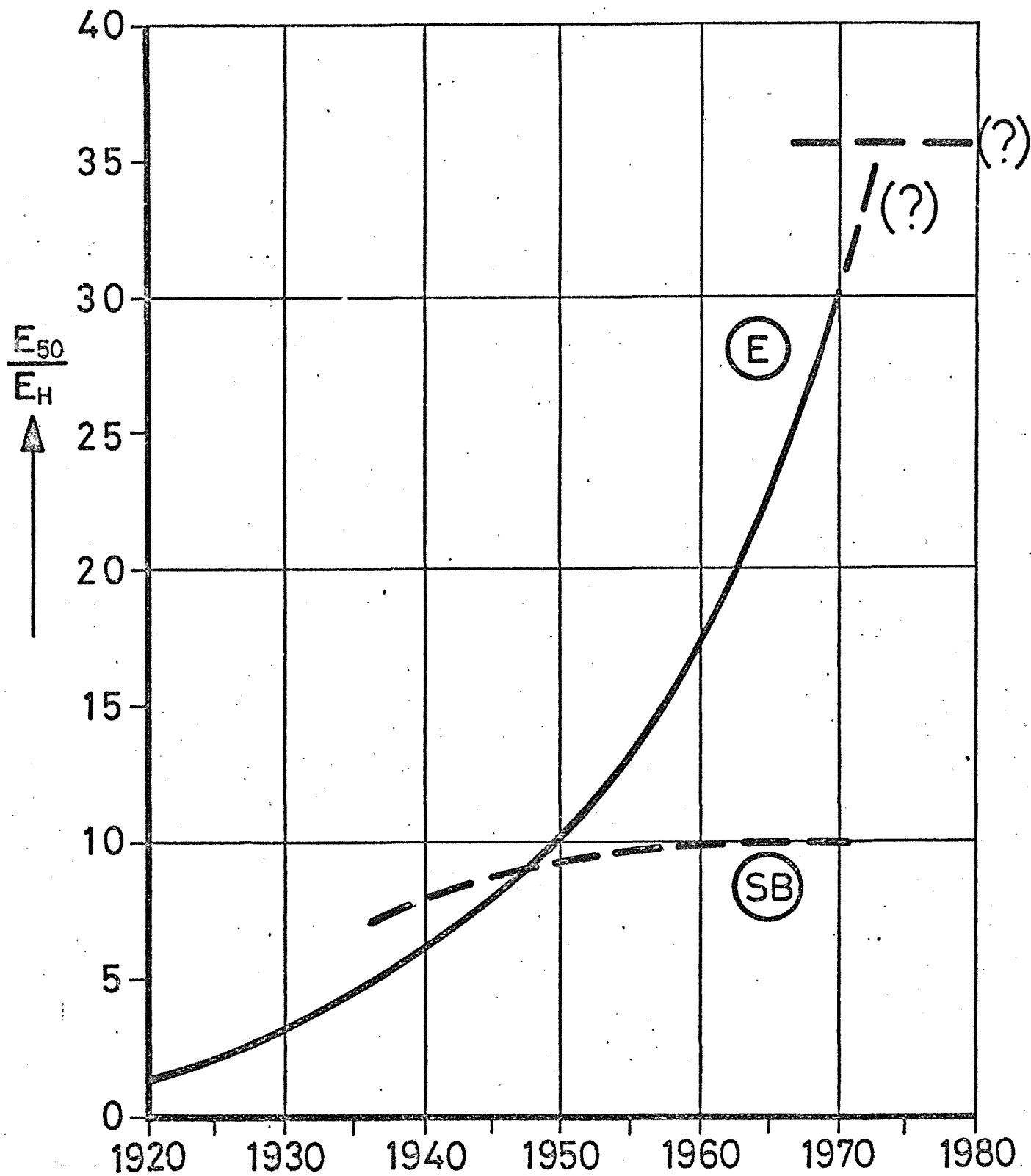
Figure A5.4. Cumulative frequency distribution of vertical aim of vehicle headlamps. 1: cars, 2: trucks (based on data of Glover, 1963).

Figure A5.5. Change of position due to loading of cars and light trucks (after Hignett, 1970).

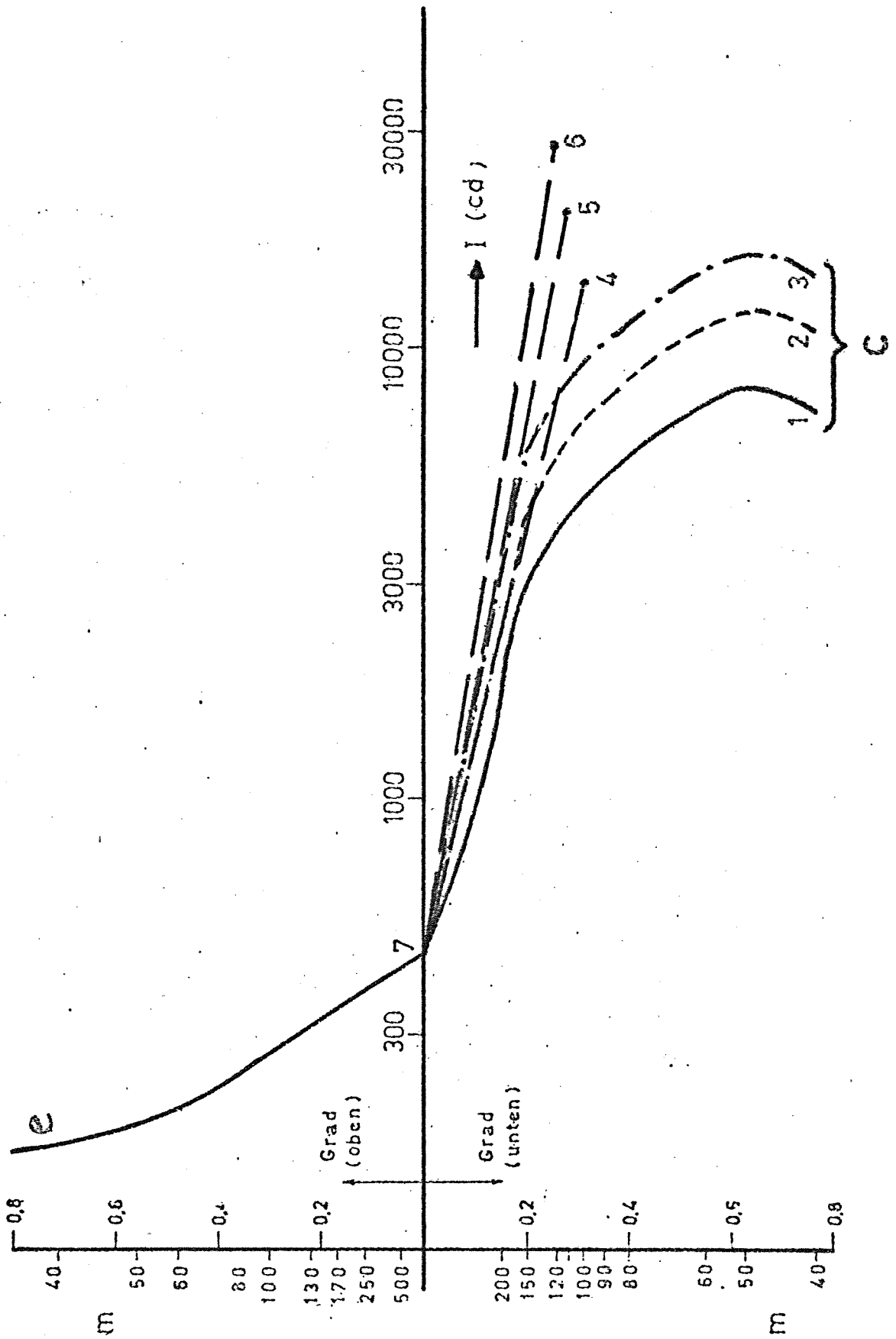
Figure A5.6. Effect of vehicle loads on headlamp aim. Headlamps aimed with  $\frac{1}{2}$  tank of full. Test vehicle 1967 Ford Custom 500. I tank empty, II tank one/half full, III tank full. A: vehicle unloaded, B: driver and passenger (after Walker, 1972).

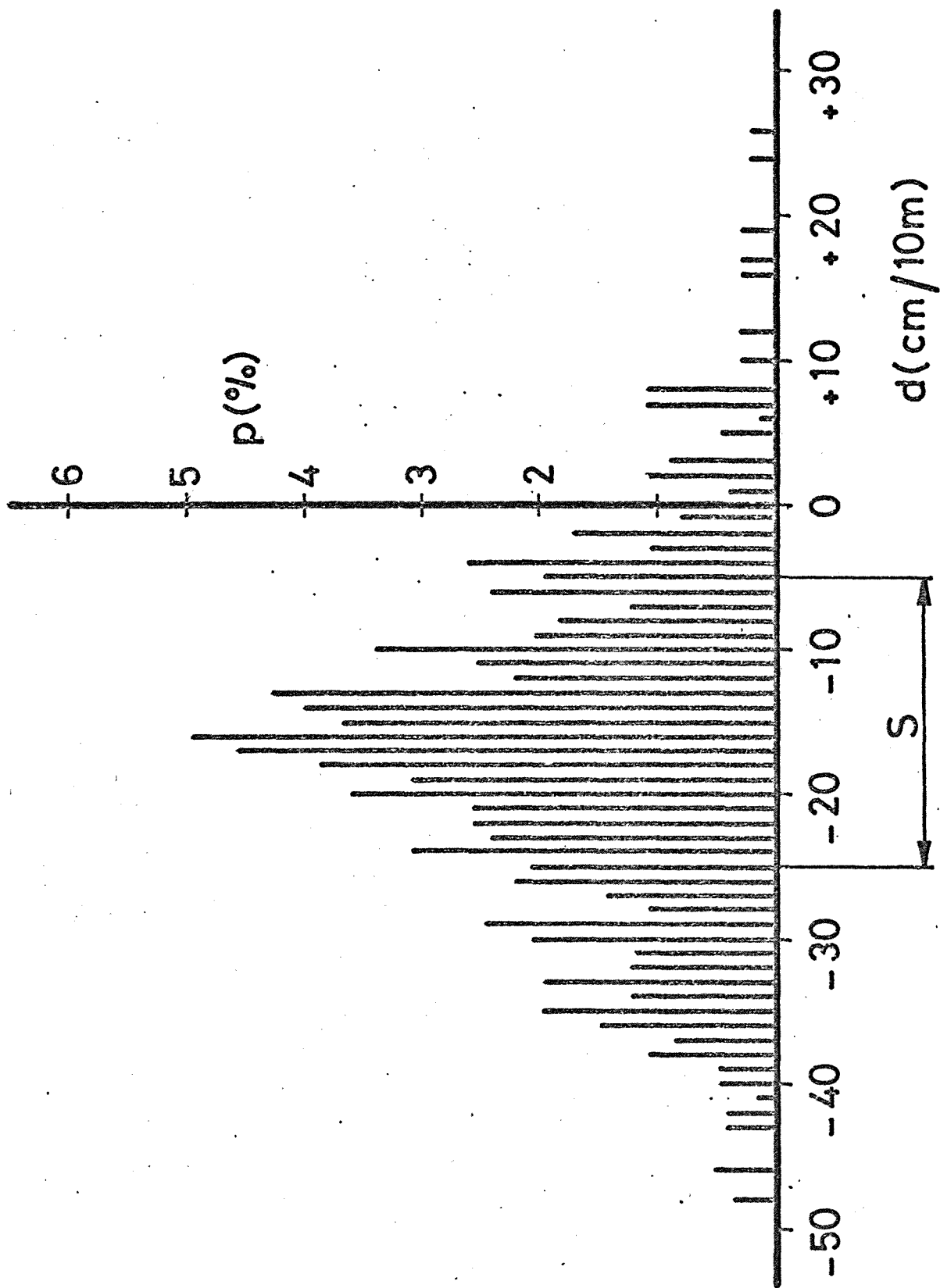
Figure A5.7. Frequency distribution of cars (p) exceeding the indicated glare intensity ( $I$  in cd) o Belgium o Netherlands  $\Delta$ Germany  $\blacktriangle$ France —calculated mean (after Yerrell, 1971).

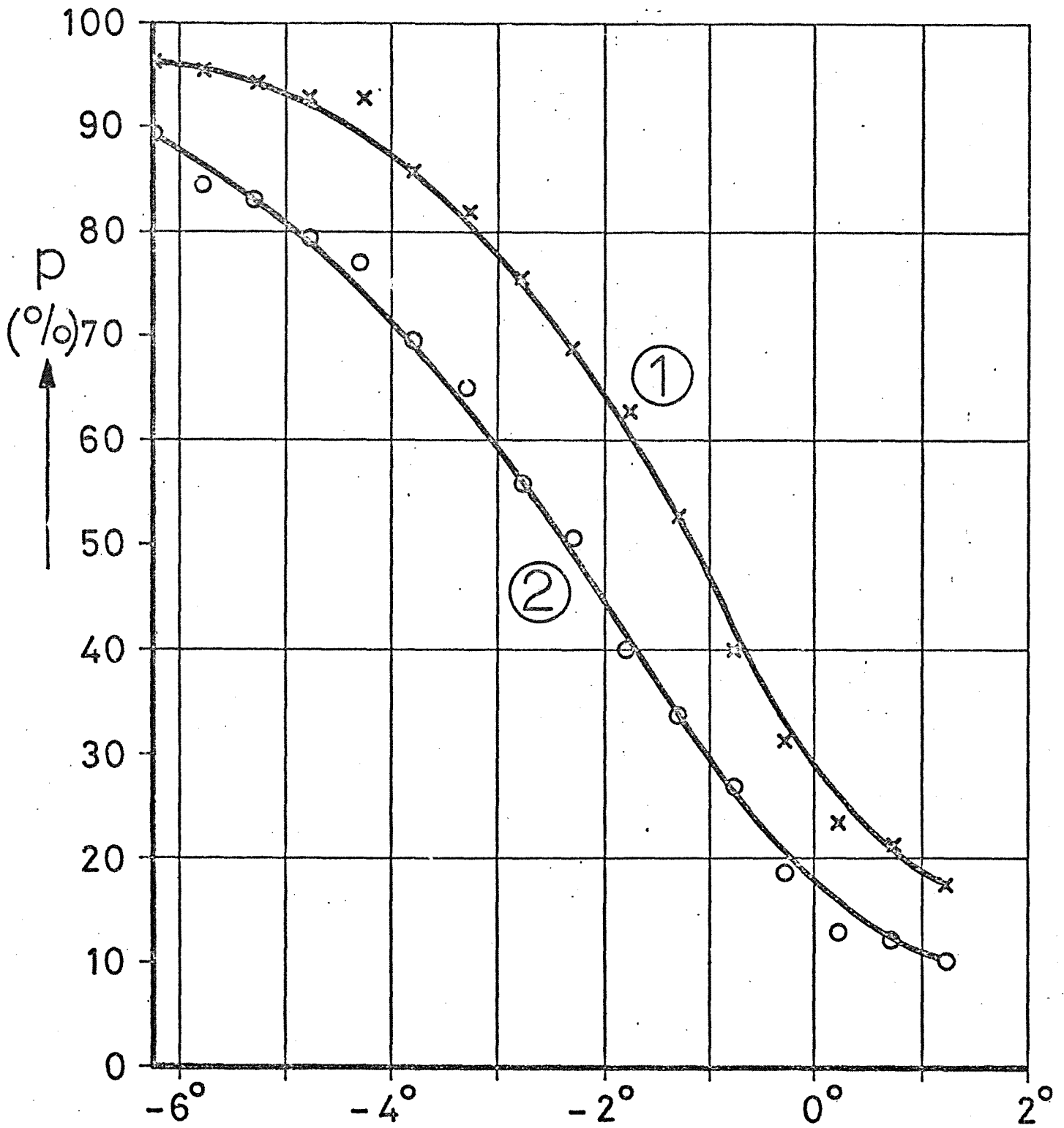


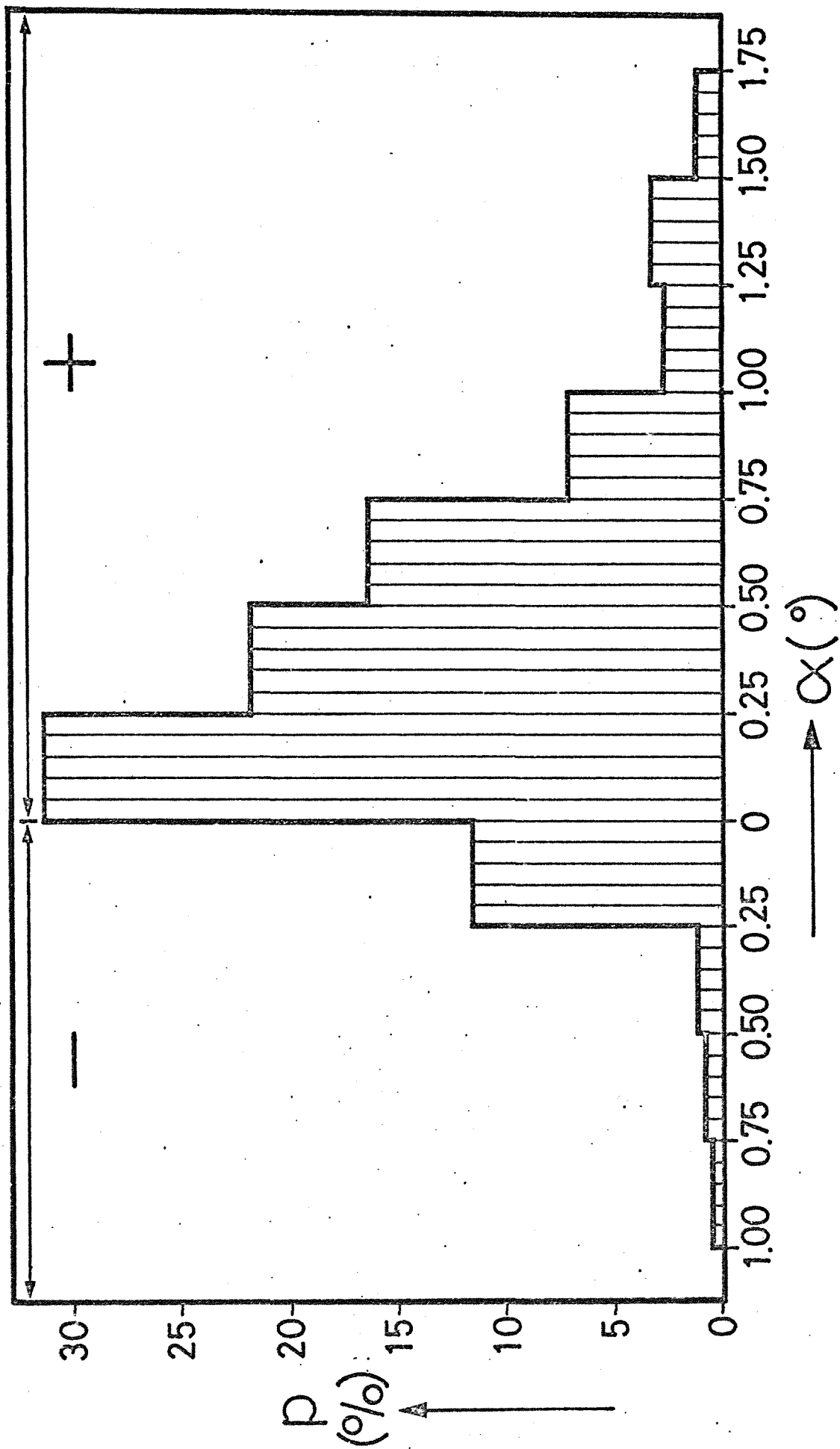


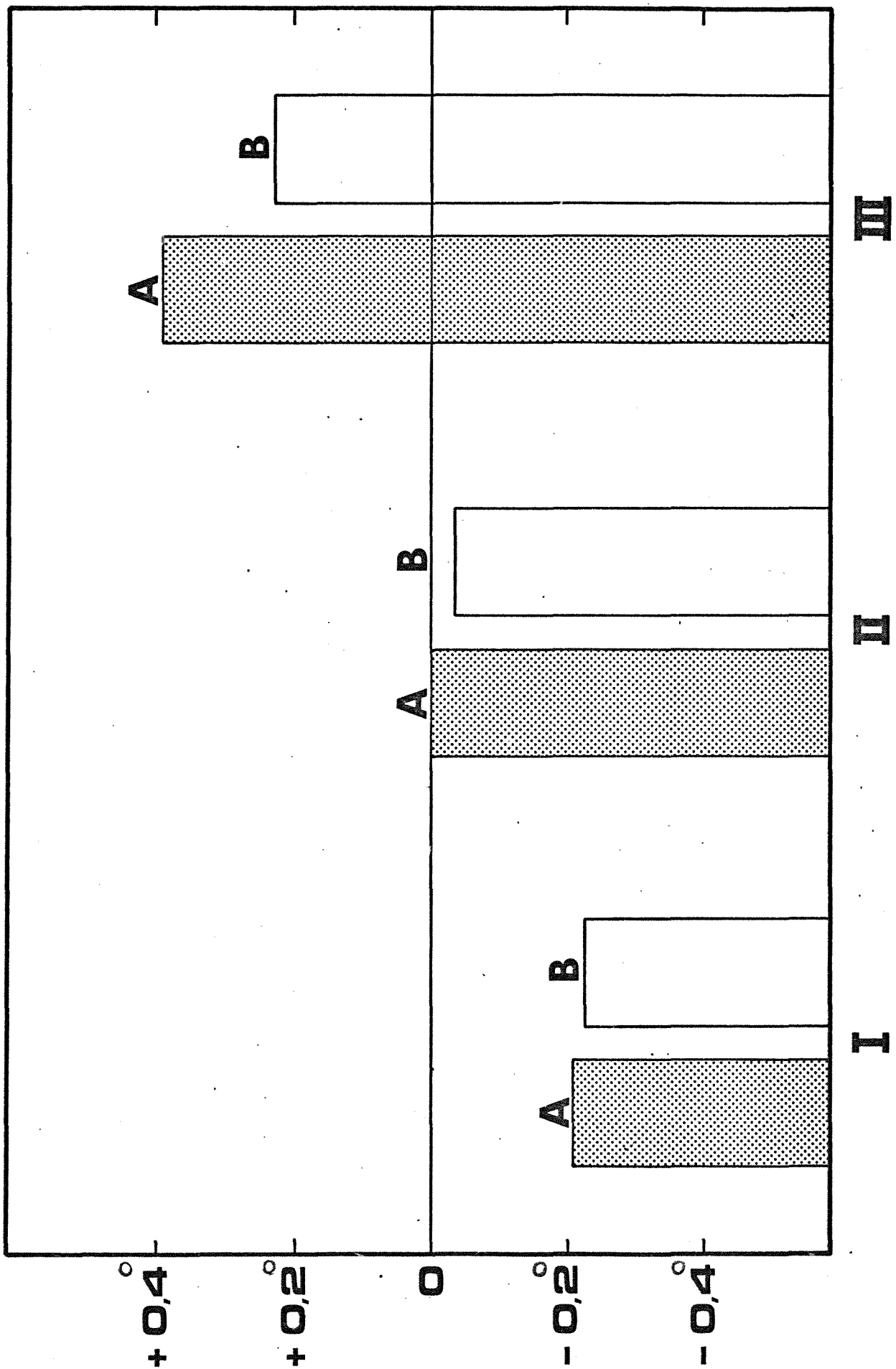


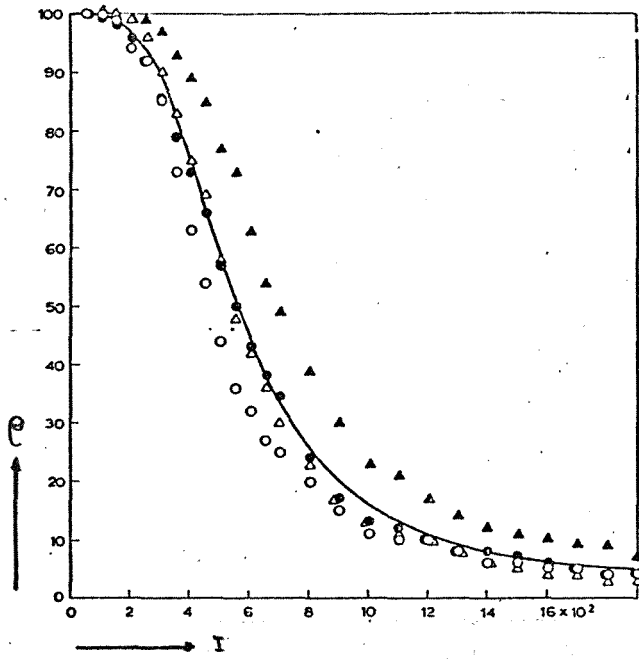












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