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HEADLAMP HISTORY AND HARMONIZATION

David W. Moore

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16. Abstract					
<p>This report describes the development of automobile headlamps. The major topics covered include the following: the reasons for the emergence and use of different light sources, headlamp materials, optical controls, and aiming methods; differences between U.S. and European headlamp practices; evolution of regulatory beam-pattern requirements; and harmonization activities.</p>					
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Introduction

A vehicle without headlamps? A vehicle with oil burning lanterns? A vehicle with the same type of headlamps in the U.S. and Europe? Yes, these are all real conditions that existed “once upon a time.” This report will describe the early headlamps and beam patterns; discuss some of the differences in headlamps in the U.S. and Europe; describe some of the improvements in technology that have occurred; and finally comment on current harmonization activities.

19th Century

Horse drawn carriages were the primary mode of transportation before the advent of the automobile. These carriages had lamps with candles and oil burning lanterns. The automobile did not appear until the late 1880s. At first there was no lighting on a vehicle and no nighttime driving. Although the electric light bulb was invented by Thomas Edison in 1879, the first lighting on automobiles was not electric headlamps. When people started driving at night, the first vehicle lighting devices were oil (kerosene) burning lanterns. Photographs of several early European vehicles and their kerosene lamps are shown by Drach (1993). These lighting devices provided a signal to drivers of other vehicles and carriages, and also to pedestrians. They did not provide any substantial illumination on the road, which was badly needed because the roads were often in poor condition and people were not able to see objects in the road. At the turn of the century the use of the automobile was limited because people were not yet accustomed to the increased potential for mobility that it offered.

1900-1910

Automotive development in the U.S. and Europe proceeded with many aspects in common during these early years. During this time period, vehicles were equipped with kerosene headlamps and no other lighting devices. Drach (1993) estimates that kerosene headlamps were used in Europe until 1900, then carbide (acetylene) headlamps were used from 1900 to 1910. According to a French author (Devaux, 1970), electric lighting for vehicles started, in limited quantities, in 1901 with the use of a small dynamo driven by the motor flywheel. Headlamps were the only application for the generated electricity. Accumulators and a regulator added to the complexity and the cost, which was indicated to be between 800 and 2000 gold francs for the total installation—almost as expensive as the rest of the car. This basic concept, although now much less expensive, is still used on bicycles today. Drach (1993) indicates there were experiments in Europe in 1905 with electric headlamps on vehicles.

The first noticeable improvement in headlamps in the U.S. occurred in 1906 when acetylene headlamps appeared. Gas for the acetylene light source was generated by water dripping slowly onto calcium chloride in a small container (Banta, 1940). During cold weather the water would freeze, stopping the gas generation process. It was possible to partially remedy this situation by mixing alcohol in the water. These headlamps required regular cleaning of the nozzle tip where the gas flame burned. Another type of acetylene headlamp, used more on trucks, had a pressure tank containing acetylene gas absorbed in acetone. This eliminated the water and the consequent freezing problems, but still required regular cleaning of the nozzle tip. In each type, there were problems with the gas flame going out in gusting winds and rain. The light source was rather large and unstable, so there was poor control of the beam pattern. Still it was possible to obtain a beam pattern spread of about $\pm 10^\circ$ and have a maximum of 5,000 cd at the center of the basically spot beam (Anonymous, 1956). Acetylene headlamps were used on the majority of newly manufactured vehicles until 1912. Because of the limited number of cars on the road, glare at this time was not a significant problem. However, just a few years later it became an important topic of discussion within state and city governments and the automotive industry.

In 1908, the first automotive headlamp bulbs in the U.S. used a carbon filament, contained a vacuum, and were not gas filled. Electric headlamps using these bulbs and a battery were installed as optional equipment on vehicles (Anonymous, 1956). Light sources with tantalum were used briefly, but quickly the advantages of tungsten were realized. Heppenheimer (1998) describes many of the early research and development accomplishments of Irving Langmuir and inventors in Europe regarding electric light sources: carbon filaments, osmium filaments, tantalum filaments, tungsten filaments, vacuum bulbs, and finally gas-filled bulbs. Each of these technology steps, from 1900 to 1911, was first made for household electric lighting and then modified for use on automotive vehicles a few years later.

The headlamp beam pattern, using these bulbs, had a spread of about $\pm 10^\circ$, but the maximum intensity was now about 30,000 cd. Better light source control enabled this increased intensity. The only type of beam pattern available was still best described as a spot beam.

1911-1920

In 1911 the first electric headlamps were installed as standard equipment on some U.S. passenger cars. However, the volume was extremely low. In 1912 the first vehicle-wide wire harness, electric starter, and electrical system were installed (Johnston, 1996). This allowed an increased use of electric light sources and significantly increased the installation of electric headlamps

on vehicles. It was at about this time that the U.S. driver position was established on the left side of the vehicle. Consequently, all further lighting developments in the U.S. occurred with the same basic driver location as today.

Kettering (1912) discusses several of the intermediate steps in going from industrial electric light bulbs to automotive electric light bulbs. Early tungsten filaments were “sintered” and very fragile. After several attempts, drawing or extruding was discovered as a means of making reasonably ductile tungsten wire.

At this time, most headlamps used a 21-candlepower bulb. Kebler (1912) claims that with a shallow parabolic reflector this light source would light a road 50 feet (15 m) wide for the full width of the road from the front of the car to a point over a quarter of a mile away. (*Maybe some of that technology should be used today.*)

According to Drach (1993), electric headlamps were installed as original equipment on European vehicles starting in 1913, which correlates closely with the installation on U.S. vehicles.

In 1915 tungsten filament bulbs filled with nitrogen gas were first used in automotive applications (Carlson, 1929). Adding the inert gas reduced the tungsten evaporation and allowed the filament to last longer. The lens, or more correctly the cover, did not initially have any optical elements so there was no bending or spreading of the beam pattern.

The first lighting regulation was adopted in the state of Massachusetts on October 27, 1915 (Devine, 1921, p. 507):

This regulation provided that wherever there was not sufficient light on the highway to make all substantial objects visible for a distance of at least 150 feet (45.7 m), the lamps which a motor vehicle was required to display, should throw sufficient light ahead to make clearly visible any such object within the specified distance. They provided further that any light thrown ahead or sidewise should be so directed that no dazzling rays should at any time be more than 3.5 ft (1.1 m) above the ground 50 ft (15 m) or more ahead of the vehicle, and that such light should be sufficient to show any substantial object 10 ft (3 m) on each side 10 ft (3 m) ahead of the vehicle.

Instances of the difficulty of police enforcement of this regulation are described by Devine (1921). Attempts were made by motorists to diffuse the glare by attaching pieces of frosted glass or other “glare eliminating devices” to the front of the headlamp. Devine concludes that “it became apparent as time went on that the regulations were not very effective” (p. 508). Baltimore, Maryland, passed an ordinance which limited glare but did not control visibility (Replogle, 1917).

Schroeder (1916) and McMurtry (1917) provide illustrations of the many different bulb sizes and filament shapes being used. These bulbs were made by different manufacturers for headlamp applications. The bulbs included simple transverse filaments, coiled-coiled spiral axial designs, and center supported V-shaped coils. The size of these filaments prevented reasonable control of the

beam pattern. The output of some of the bulb designs varied from 135 to 584 lumens. However, even then lighting engineers were concerned with glare and visibility (Clark, 1916; Replogle, 1917; McMurtry, 1917).

Passenger car headlamps were located approximately 107 cm above the road and the approximate location of the driver's eyepoint was 137 cm above the road (Clark, 1916). In comparison, the corresponding values for 1996 passenger cars in the U.S. were 62 cm and 111 cm, respectively (Sivak et al., 1996).

Many headlamps were equipped with gadgets and “glare-preventing” devices to satisfy the concerns being raised by drivers and being written about in the technical literature. One common method was to switch a resistor into the headlamp circuit to reduce the current to the headlamp bulb filament. Some headlamps were built with reflectors tiltable from the driver's seat. As another vehicle approached, the reflector would be tilted downward. Another more sophisticated method used a vacuum connection from the intake manifold. A bellows, on the top of the headlamp reflector, was connected to the vacuum line and held the reflector in the correct position until the driver turned a valve closing the vacuum line, then the bellows expanded tilting the headlamp reflector downward (Banta, 1940). Also, some installations had electric methods of tilting the reflector (manual headlamp leveling). However, most of these devices did not work well. Headlamp bulbs did not have accurate location of the filament with respect to the base. The positioning of the bulb in the headlamp assembly also left room for improvement. Each of these situations contributed to glare.

Grondahl (1921) describes a method for minimizing glare from filament mislocation. Using two designated areas on the lens, the filament images will only converge to one specified point when the filament is located at the focal point of the parabola. If the images don't converge, then an adjustment needs to be made. This same method could also be used to aim the beam pattern down to reduce glare. (This general idea was discussed in the NHTSA (National Highway Traffic Safety Administration) Regulatory Negotiation meetings in Washington, D.C. in 1995-1996 for visual/optical headlamp aim (NHTSA, 1996). No one realized then that it was a 1921 idea.)

Along with technical product developments, standards and regulations were also being written. In 1918, the first joint IES (Illuminating Engineering Society) and SAE (Society of Automotive Engineers) specification relating to optical performance of headlamps was developed. Vehicles only had one beam, much closer to a high beam than what is now considered a low beam. Four test points were determined for measuring the beam pattern. The specification was written for the combined light output from both headlamps on a vehicle—the first instance of a vehicle-based specification. The complete specification was as follows (Sharp, 1921, pp. 478-479):

Measurements shall be made at the following positions at a distance of 100 ft (30.5 m) ahead of the headlamps:

Position 1. Directly ahead and at a height not less than one-half the distance of the center of the headlamps above the level surface. The indication of the foot-candle meter shall be not less than 0.48 ft-c (5.2 lux) for a motor vehicle and not less than 0.24 ft-c (2.6 lux) for a motor cycle.

Position 2. Seven feet (2.1 m) to the right of Position 1 at any point not above the level of the headlamps. The indication of the foot-candle meter shall be not less than 0.12 ft-c (1.3 lux) for a motor vehicle and not less than 0.06 ft-c (0.6 lux) for a motor cycle.

Position 3. Directly in front, 5 ft (1.5 m) above the level surface. The indication of the foot-candle meter shall be not more than 0.24 ft-c (2.6 lux).

Position 4. Five feet (1.5 m) above the level surface and 7 feet (2.1 m) to the left of the axis of the vehicle. The indication of the foot-candle meter shall be not more than 0.08 ft-c (0.9 lux).

Note—In order to allow for any possible inaccuracies of a test of this character, a tolerance of 20 per cent may be allowed on the above values.

Figure 1 shows the test point locations and intensity values for this beam pattern. A headlamp mounting height of 90 cm (Carlson, 1925) was used to establish the locations of Positions 1 and 2.

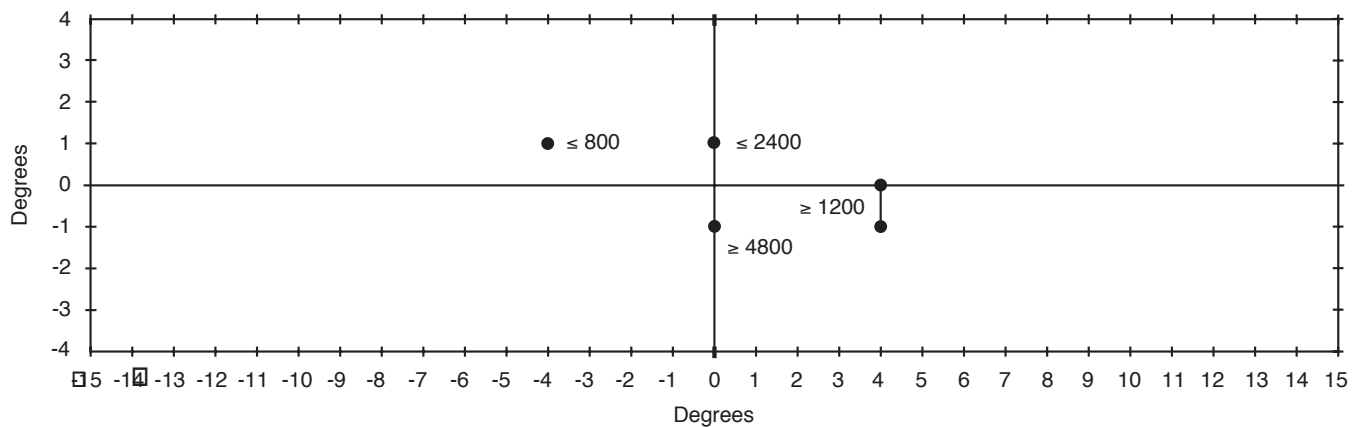


Figure 1. 1918 IES/SAE headlamp standard. Vehicle tested with both headlamps lighted. Intensity in candela (cd). Adapted from Sharp (1921).

Perhaps the first documented study of headlamp performance was done in 1920 (Devine, 1921). Thirty headlamps were obtained and photometered in a test laboratory developed for the state of Massachusetts. These headlamps were then used on road tests to compare laboratory photometry with on-road performance. These headlamps used 1 3/8 inch (35 mm) focal length parabolic reflectors and were 9 inches (229 mm) and 9 1/4 inches (235 mm) in diameter. The glare limits listed above were found to be reasonable, while it was determined that additional light was necessary for seeing objects on the road.

1921-1930

Another early study was conducted by engineers at GE Nela Park in Cleveland (Magdsick and Falge, 1921). Observers determined the amount of light in various parts of the beam pattern that “would satisfy the driver from the standpoints of safety and afford a reasonable degree of convenience in operating the car” (p. 483). This was a thorough and comprehensive study conducted on city and country roads, and in different weather conditions. The study also included comments about the legislative activities in several states.

The results of the above-discussed studies led to a 1922 revision of the IES-SAE photometric requirements for headlamps. Test points were added and the “seeing light” values below the horizontal were increased (see Figure 2).

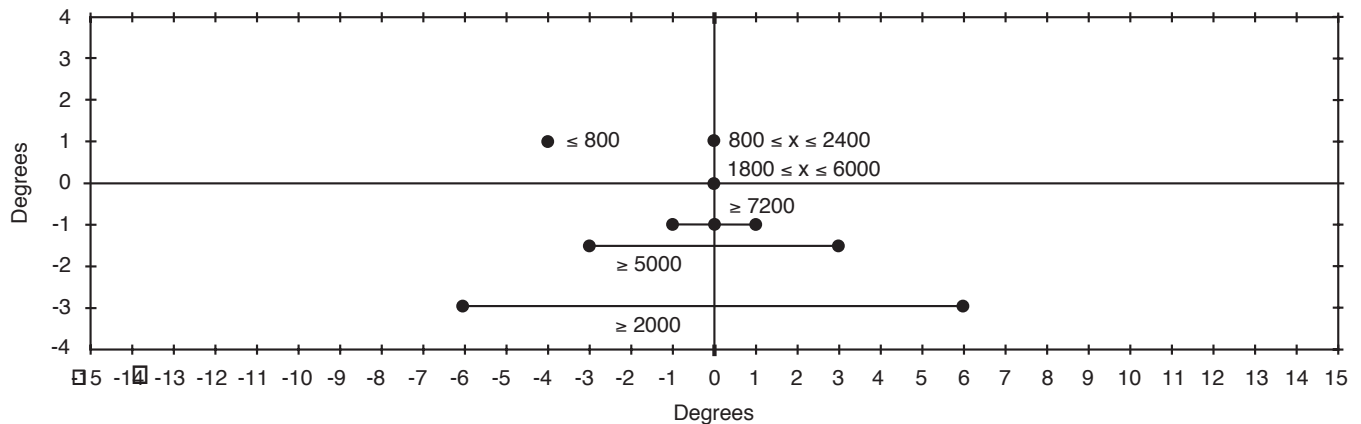


Figure 2. 1922 revised IES/SAE headlamp standard. Vehicle tested with both headlamps lighted. Intensity in candela (cd). Adapted from SAE (1926).

During this decade, inspection stations were established in various states, with the requirement that drivers of vehicles obtain a certificate indicating the headlamps were properly aimed, had sufficient light output, and did not cause excessive glare. There were discussions at this time to specify a minimum light value above the horizontal line, to adequately illuminate “low hanging trees and other obstructions from above” (Devine, 1921, p. 527). Indeed, a minimum light value above the horizontal line was included in the 1922 revision (see Figure 2).

The early developments regarding vehicle headlamps were similar for the U.S. and Europe. Bulbs, lighting components, and beam patterns were essentially the same (Devaux, 1970; Meese, 1972; Maurer, 1980). However, in the 1920s two different approaches to automotive lighting began

to appear. Much of this can be attributed to the more rapid increase in the vehicle population in the U.S. than in Europe. There were also differences in the use of the automobile. Americans more quickly adapted to mobility provided by the automobile, cities expanded, people began moving to the suburbs, and industry developed outside of the center of the downtown area. Americans drove their cars more on the open roads and did more night driving. Europeans retained more of the focus on the center city area and daytime driving. It is generally acknowledged that these factors contributed to the two different approaches (Nelson, 1954; deBoer, 1955; Meese, 1972; Olson, 1977). The two approaches can be summarized as follows:

- (1) Primary emphasis: Develop as much light as possible to maximize seeing ahead of the vehicle. Secondary emphasis: Consider the other driver and try to do something to minimize glare. (U.S. philosophy)
- (2) Primary emphasis: Do whatever is necessary to minimize glare in the other driver's eyes. Secondary emphasis: Try to make sure there is available light to drive. (European philosophy)

Rules and specifications prepared by the IES were submitted to the American Engineering Standards Committee for adoption as a tentative U.S. standard (Sharp, 1921). These same rules and specifications were then submitted for consideration to the International Commission on Illumination (Commission Internationale de l'Eclairage, CIE) for a 1921 meeting. At that meeting the following resolution was adopted (Sharp, 1921, p. 470):

The International Commission on Illumination records its strong opinion that regulations respecting limitations of the light from automobile headlamps should be framed with reference to international agreements so that the regulations may be uniform for all countries. (*Is this the first attempt at headlamp beam pattern harmonization?*)

At that meeting, a committee was established to study the problem of automobile headlighting and to report at the next session of the Commission. (*There are groups still working on this in 1998.*)

In the U.S., the IES was working on improving the details of their first rules. It was decided to only consider 21-candlepower bulbs in headlamp sizes of 8 5/32 inch (211 mm), 8 1/2 inch (216 mm), 9 inch (229 mm), and 9 1/2 inch (241 mm) diameter.

Before 1924, all headlamps generated a single beam pattern, best described as a spot beam resembling today's high beam. In the middle twenties the first two-beam system was developed (Moore, 1958). The two-filament automotive bulb was invented, which enabled a high- and low-beam pattern to be created in one headlamp assembly. In these bulbs, the high-beam filament was placed on the focal point and the low-beam filament was mounted above and to the left. Thus, when

switched to the low beam the beam pattern moved down and to the right (side shifting). This arrangement of the filaments continued until the middle 1950s in U.S headlamps.

Europeans were also making changes in the bulbs they used. Two-filament bulbs with an internal bulb shield were manufactured to help reduce glare light. The internal bulb shield yielded a symmetrical flat-topped beam pattern. In general, this type of beam pattern lasted in Europe until after World War II.

1931-1940

One approach used in the U.K. to somewhat control glare had a movable reflector assembly to be used when another vehicle approached. This assembly was tilted downwards and to the nearside (left side of the road in the U.K.) by means of an electromagnet operated by a switch under the control of the driver. The switch also caused the offside (right side of the vehicle in the U.K.) headlamp to be turned off (Moore, 1958).

Several different combinations of beam patterns were developed in the U.S. to try to provide improved lighting with some measure of glare control. Three-filament bulbs were developed to create four beam patterns: a regular high beam, a regular low beam, a meeting beam to use when approaching other vehicles, and a super high beam for straight roads in the country with no opposing traffic. These headlamps were used on some cars in 1932 and 1933. Three-beam headlamps had a “traffic beam” aimed high on the right and low on the left, in addition to the regular high and low beams. Thus, an automobile might have included a single beam, two beams, three beams, four beams, or side shifting beams (Banta, 1940).

By the middle 1930s many states had lighting regulations intended to control glare. Creative inventors had developed diffusers, intensity reducers, masks, etc., in an attempt to deal with glare. Headlamps were of many different sizes, and the mechanisms for aiming these headlamps were not all reliable. Some involved bending of sheet metal brackets, while others called for moving the bulb position inside a headlamp. All of these attempts only caused state officials to enact more regulations (Meese, 1983). Lighting engineers, automotive manufacturers, and state officials were all trying to do something to provide better lighting with lower glare. During these discussions SAE prepared a revised beam pattern (SAE, 1933). This pattern is shown in Figure 3.

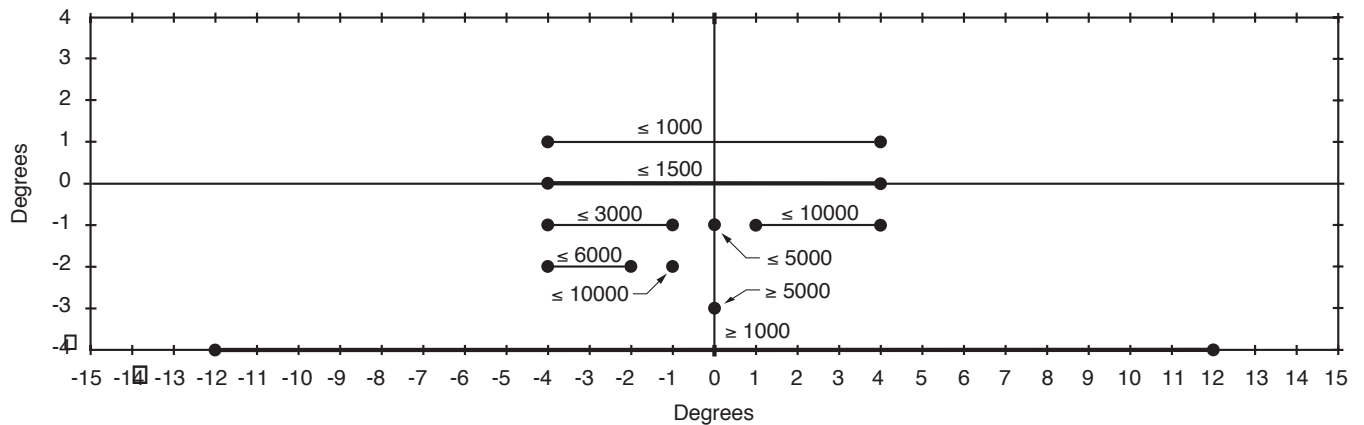


Figure 3. 1933 SAE low beam standard. Intensity in candela (cd). Adapted from SAE (1933).

In 1937 France legislated that headlamps emit (selective) yellow light (Jehu, 1954; Nelson, 1954). The French gave the following reasons for requiring yellow light: improvements in visibility under conditions of glare, and, even more important, reductions in fatigue under glare conditions. The yellow headlamp color was obtained by several different methods: a glass bulb with a different chemical composition, coatings on the glass bulb, a yellow headlamp lens, or a yellow filter. Because the yellow glass for bulbs reduced the emitted light intensity by about 18% (Jehu, 1954), this may have contributed to the perception of reduced glare from yellow headlamps. Many tests were run in different countries which failed to show any significant advantage in favor of yellow headlamps (Schreuder, 1976). However, within France, the mandatory use of yellow headlamps continued until the early 1990s.

By the late thirties, the dissatisfaction with the conditions of headlamps in the U.S. had reached such a level that something new was needed. Headlamps had metal reflectors with a silvered reflecting surface (which tarnished and had to be polished), nonstandardized metal-based bulbs inserted into the reflector, no O-rings on the bulbs for sealing, and no common method for either mechanically aiming the headlamp or visually/optically aiming the beam pattern. The glass sealed beam headlamp was patented and became the answer to most of the above problems. The sealed beam consisted of two pieces of glass, a lens with optics, a parabolic aluminized reflector, and tungsten filaments supported by metal lead wires. The two glass pieces were fused (melted) together, and the assembly was filled with an inert gas to prolong the life of the tungsten filaments. Within two model years, 1940 and 1941, all U.S. car production switched to one common headlamp size, 7 inch (178 mm) round, with two headlamps per vehicle. Nelson (1954) states that the all-glass sealed beam

headlamp was probably the most advanced control of an automotive lighting product sold to the general public at that time. Because of patent restrictions, some “sealed beam headlamps” were made with a metal reflector, a soldered-in bulb, and a glass lens permanently fastened together. These metal-backed “sealed beams” were finally phased out by the middle fifties, when the entire U.S. headlamp industry began making only all-glass sealed beam headlamps. In 1940 the maximum intensity per vehicle was raised from 50,000 cd to 75,000 cd (Oliver, 1980). Also, SAE revised the low-beam specification by decreasing the allowed glare light and increasing the minimum required values below the horizontal line (see Figure 4).

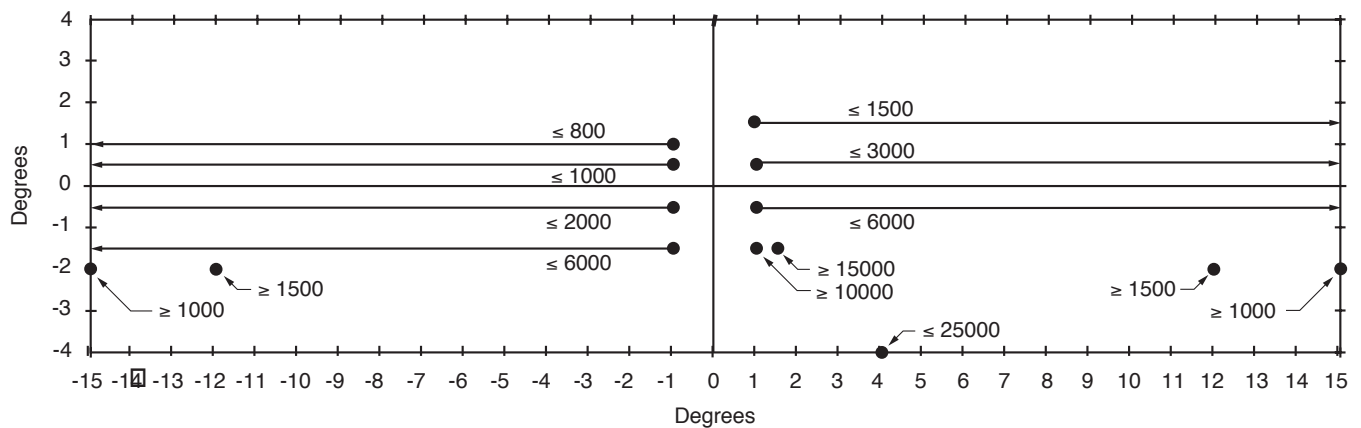


Figure 4. 1940 SAE low beam standard. Intensity in candela (cd). Adapted from SAE (1945).

1941-1950

This decade did not have significant technical advances in headlamp design. After World War II there were many American-made automobiles on European roads equipped with U.S. beam pattern headlamps (deBoer, 1955). This accelerated the evaluations and comparisons of U.S. and European headlamp beam patterns that occurred in the early fifties.

1951-1960

At the beginning of this decade, all U.S. headlamps were as follows: 7 inch (178 mm) round sealed beams with high-beam filament on focus, low-beam filament off focus, visual aim, and more consistent lighting than previously obtainable. European headlamps had replaceable bulbs with an

internal bulb shield on the low-beam filament, a symmetric low-beam pattern, visual aim, and continued emphasis on the accuracy of the filament location (Devaux, 1970).

Headlamp beam patterns were different in the U.S. and Europe. Lighting engineers, lighting manufacturers, and vehicle manufacturers organized a series of tests to try and develop a common beam pattern (deBoer, 1955; deBoer, 1956; Kazenmaier, 1956; Devaux, 1970). These tests were the origin of the Groupe de Travail-Bruxelles 1952 (GTB)—an international group of experts from light-source, lighting-device, and vehicle manufacturers. Even with the driving evaluations and the considerable research that was done, it was not possible to reach a compromise on one common beam pattern. The different priorities for minimizing glare versus maximizing seeing light were the main reasons for the lack of compromise. On the positive side, during this time there was a common aiming method (visual aim) in both Europe and the U.S. Mechanical aim in the U.S. did not gain industry-wide acceptance until later.

An improvement in 7 inch (178 mm) round headlamps occurred in 1954 (Oliver, 1980). Wattage was increased from 40 to 50 watts for the high-beam filament and from 30 to 40 watts for the low-beam filament. The reflector axis was tilted down, which changed the way the optical prescription was generated; the low-beam filament was placed on focus; and an external shield or “fog cap” was installed to block the direct forward light from the low-beam filament.

In 1956 “aim tips” or “aim pads” were added to the front of the glass lens to enable mechanical aiming (Olson, 1977). Previous to this, the SAE Lighting Committee and other industry groups had many tests with participants visually aiming U.S. beam pattern headlamps. The results indicated that visual aiming of the existing U.S. beam patterns was not very accurate. Mechanical aim removed the subjectivity of trying to visually aim the U.S. beam pattern. Mechanical aim for headlamps later became the sole required method in the U.S. (until 1997).

Although there had been some limited earlier installations of four headlamps on a vehicle, most vehicles only had two headlamps. When the low beam and high beam are obtained from the same lens area, there is a compromise in the optical prescription. In 1957 the 5 3/4 inch (146 mm) round four-headlamp system was developed in the U.S. (Roper, 1957). There was a high-beam headlamp, and a separate headlamp primarily designed for the low beam, but with a secondary filament to provide some fill light on high beam. Thus, the lens optics compromise was eliminated, because each headlamp had a single primary function.

1961-1970

One characteristic of tungsten filaments is that the tungsten evaporates while the light source is on. This evaporation process will concentrate at some weak spot, scratch, or mark on the tungsten surface. After many hours the tungsten becomes thinner and finally the filament will burn out. The concept of the halogen cycle, and the benefits regarding redeposition of evaporated tungsten on the filament were discovered in 1912 (Ehrhardt, 1979). Certain halogen gases, when inserted in a bulb, combine with the evaporating tungsten molecules to form a compound that will circulate back to the filament, where the tungsten will dissociate and redeposit on the hot filament. This allows the filament to burn brighter and hotter without shortening its life. However, it is not perpetual motion, and eventually halogen bulbs will also burn out. Automotive applications of halogen headlamp bulbs did not occur until the middle sixties. Europe was quicker to take advantage of this improved light source than the U.S. Single filament H1, H2, and H3 light sources were made and used in headlamps and other lighting applications on vehicles in Europe. The double-filament H4 bulb was used in the late sixties in European headlamps. Halogen bulbs were not installed in U.S. sealed beam headlamps until the 1970s. Some refinements in the low-beam headlamp specifications occurred in 1965 when SAE J579a was written (see Figure 5).

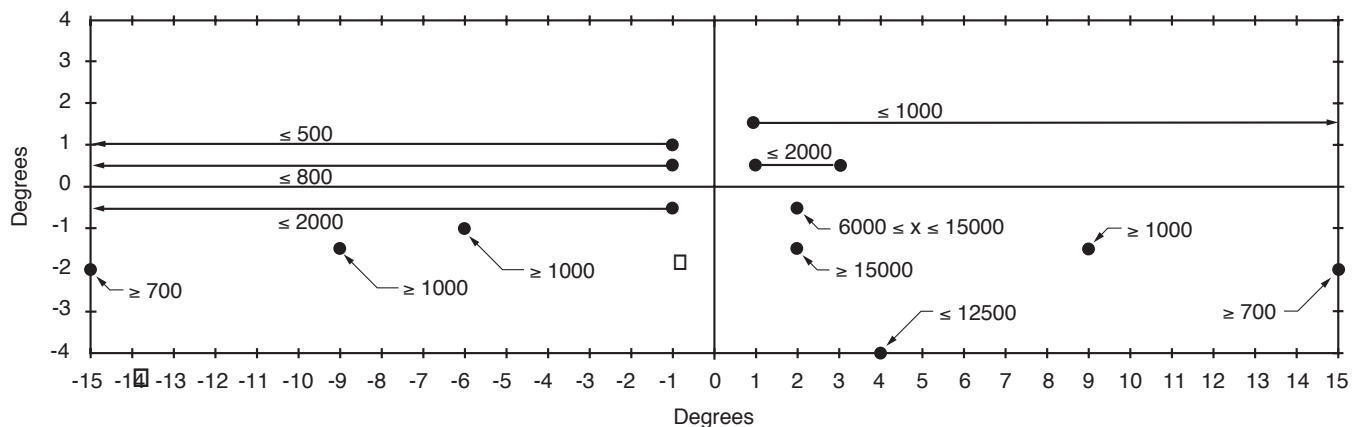


Figure 5. SAE low beam standard J579a. Intensity in candela (cd). Adapted from SAE (1965).

The U.S. government passed the Motor Vehicle Safety Act in 1966. The U.S. National Highway Traffic Safety Administration (NHTSA) was created in 1968 to improve the safety of road transportation by focusing on the design of vehicles. Previously, lighting was regulated solely by states. Within two years, many existing SAE lighting standards were adopted, in whole or in part, in the Federal Motor Vehicle Safety Standards (FMVSS).

1971-1980

At the beginning of the 1970s two headlamp sizes were legal in the U.S.: 7 inch (178 mm) round (two headlamps per vehicle) and 5 3/4 inch (146 mm) round (four headlamps per vehicle). In 1974 NHTSA approved a petition to allow a new four-headlamp rectangular sealed beam system, 4 inches by 6 1/2 inches (100 mm by 165 mm). Two years later, a 142 mm by 200 mm rectangular two-headlamp system was allowed. Then in 1978, NHTSA increased the maximum allowed headlamp intensity per vehicle from 75,000 cd to 150,000 cd (NHTSA, 1978). This made the installation of halogen bulbs in sealed beam headlamps advantageous, because seeing distance could be improved with the additional lighting intensity.

Most headlamps in the world had used glass lenses up to this time. With the use of halogen light sources in the U.S., the hermetic seal provided by the all-glass sealed beam was not required. In halogen lamps the tungsten filament was contained in a gas-filled inner glass bulb. Adhesive-bonded, all-glass sealed beams were manufactured along with sealed beams with plastic lenses and reflectors. Materials and coatings were developed to provide good abrasion resistance, and the plastic materials increased the impact resistance to stone breakage.

During this time period, Europe had a higher percentage of headlamps with halogen bulbs than the U.S. Most European headlamps used replaceable bulbs. Some European countries allowed sealed beams (a very small percentage of the total number of headlamps) meeting the ECE beam pattern requirements.

1981-1990

In 1983 NHTSA, responding to a petition, approved the use of a standardized replaceable halogen bulb (9004) in U.S. headlamps. The first aerodynamic/composite/replaceable-bulb headlamp in the U.S. was for the 1984 model year. Within a few years a majority of U.S. automobiles were designed with this new style of headlamp. Plastic lenses and housings quickly became the materials used, because they provided improved headlamp performance and increased styling flexibility. Other sealed beam sizes (e.g., 92 mm by 150 mm in 1986) and additional halogen replaceable bulbs (e.g.,

9005 and 9006 in 1987) added to the variety of headlamp assemblies that could be installed on U.S. vehicles.

Research-and-development work on HID (high-intensity discharge) lighting systems was being done all over the world. Again this was not a new technology, but the application for automotive use took many years from its first use in commercial buildings. Problems concerning startup and quick restrike (turning the headlamp off and on within a few seconds) were finally solved at an acceptable level.

Although the early lighting literature indicates that limited attempts were made to use something other than a parabolic reflector, most headlamps from the very beginning of automotive lighting used a parabolic reflector to collect the light from the source. European engineers, using predominantly the H4 light source, began to employ a segmented reflector, but the basic surfaces were still parabolic (Spencer, 1984). The next step was to develop multisegmented surfaces (Spencer and Manunta, 1987). Then, as optical computer-lighting programs were developed, smooth computer-generated surfaces were designed to form the beam pattern without having any optics in the lens (Fratty, 1987). The first production use of a clear lens-complete reflector optics headlamp was in 1989.

Ellipsoidal surfaces for headlamp reflectors were first attempted early in the history of headlighting (Department of Commerce, 1925; Ehrhardt, 1992). In 1985, ellipsoid headlamps (also called projector lamps) were developed (Lindae, 1985). They were first installed as production headlamps in a German bus (Neumann, 1994). Many other automobiles and trucks started using this type of headlamp assembly during the following years. The advantages are smaller headlamp vertical height, more uniformity in the beam pattern, and the ability to make a sharper cutoff, or gradient, which allows more accurate visual headlamp aim.

1991-Present

In the U.S., a new headlamp (55 mm by 135 mm) was introduced that was too small for the existing field mechanical aimers. Consequently, a new method of mechanical aiming was developed. By installing a vehicle headlamp aiming device (VHAD) on each headlamp on the automobile, mechanical aim could still be accomplished. The VHAD incorporated a level bubble for vertical aim, similar to one on the field mechanical aimers. For horizontal aim, the VHAD incorporated an indicator and a reference mark on the fixed vehicle structure (to replace mirrors used on the field mechanical aimers). With VHADs, headlamps were not required to have aiming tips on the lenses.

VHADs were first installed in 1991 on the 55 mm by 135 mm headlamps, but later were installed on other types of headlamps as well.

HID low beam headlamps were first installed on production vehicles in Europe in 1991 (Huhn, 1995). In relation to tungsten-halogen headlamps, HID headlamp systems provided longer life, increased light-source lumens, higher intensity beam patterns, increased color temperature of the light source, and greater durability of the light source. All of these advantages were available at some increase in cost. Within the next few years several other car models began using HID low beam headlamps in Europe, Japan, and the U.S. Europe created new regulations for HID light sources and headlamps using HID light sources (ECE R98 and ECE R99).

FMVSS 108 now contained several alternative low-beam headlamp photometric specifications (depending on the light source and the type of headlamp system). One of the most commonly used specifications in the 1990s is shown in Figure 6.

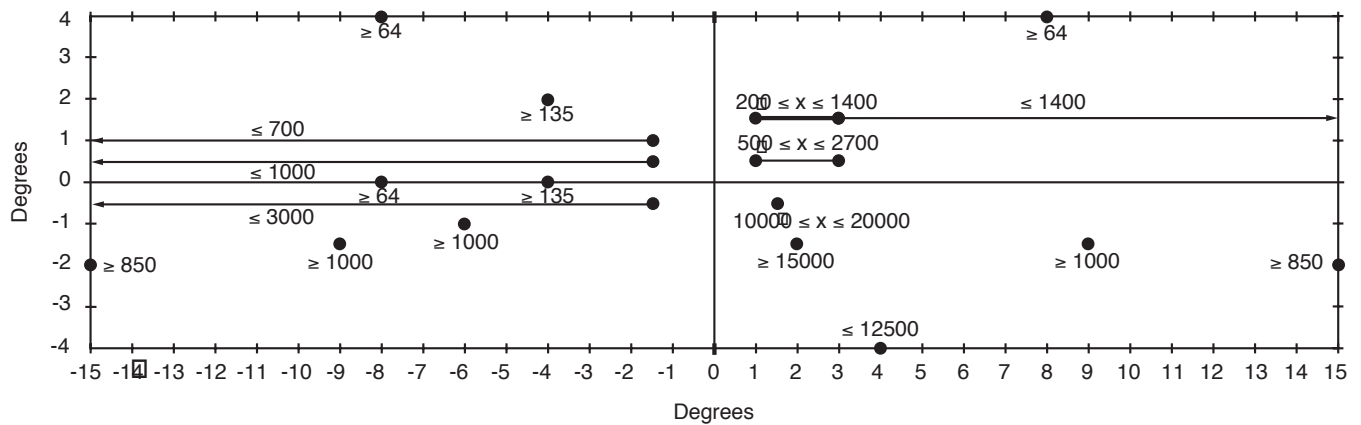


Figure 6. U.S. FMVSS 108 low beam. Intensity in candela (cd). Adapted from Office of the Federal Register (1997).

Mechanical aim, in one form or another, was the only method recognized by the U.S. government in FMVSS 108. Because of the many changes in the U.S. beam pattern in recent years, and also to harmonize the regulations with the rest of the world, NHTSA in 1995 began a regulatory negotiation process with several representatives of different companies and organizations associated with automotive lighting. The result was a rule change (NHTSA, 1997) to allow visual/optical aim for headlamps in the U.S. that meet a certain minimum vertical gradient of the beam pattern. Now the beam pattern itself could be accurately positioned in the aiming process. This change harmonized the

U.S. regulations with the rest of the world so one common aiming method could be used on all headlamps designed to meet certain specified requirements. A new beam pattern, with wider spread light and some changes in other test points, was also included in this rule change.

Headlamp beam pattern harmonization continues today. In 1990, the Group Rapporteurs Eclairage (GRE), an international group of government regulators with responsibility for lighting, asked the GTB to study and recommend one harmonized worldwide headlamp beam pattern. The GTB Coordinating Committee was established for this purpose, consisting of the chairmen of several international lighting committees. After determining a program of work, a comprehensive research study was commissioned to provide guidance in the harmonization process. This study (Sivak and Flannagan, 1993) considered expert opinion, current practice, and research evidence concerning visibility and glare. Sivak and Flannagan (1993) recommended four test points that should be made common throughout the world, as a first step towards a fully harmonized beam pattern. With slight modifications, these four test points were recommended by GTB to GRE (see Figure 7). Starting with these four test points, the rest of the beam pattern was established by the GTB Coordinating Committee to provide spread light, foreground limits, adequate overhead sign light, additional controls on glare, veiling glare limits, and gradient definition. Considerable progress has been made within the GTB, although the previously mentioned differences in priorities between the U.S. and Europe concerning glare and seeing light still exist. Changes in the beam pattern have resulted in improved seeing light and wider spread light; sufficient illumination on signs is retained without causing undue glare for oncoming traffic; and gradient values are specified that allow for relatively accurate visual/optical aim of the beam pattern. Although agreement has been obtained on almost all aspects of the low beam pattern, resolution in some areas is still needed before a recommendation can be submitted by GTB to GRE.

These most recent attempts in the GRE were initiated by Japan via JASIC (Japan Automobile Standards Internationalization Center). Most of the largest differences in headlamp beam patterns have existed between the U.S. and Europe. Japan, for many years, has used a slightly modified U.S. beam pattern inverted for driving on the left side of the road, and recently has accepted European-approved headlamps for the U.K. Japan has also indicated they will sign the United Nations “umbrella” document (1958 Agreement) for all ECE lighting regulations and will begin enforcing the ECE Regulations. Japan has accepted the above-mentioned four common test points into their appropriate headlamp standard.

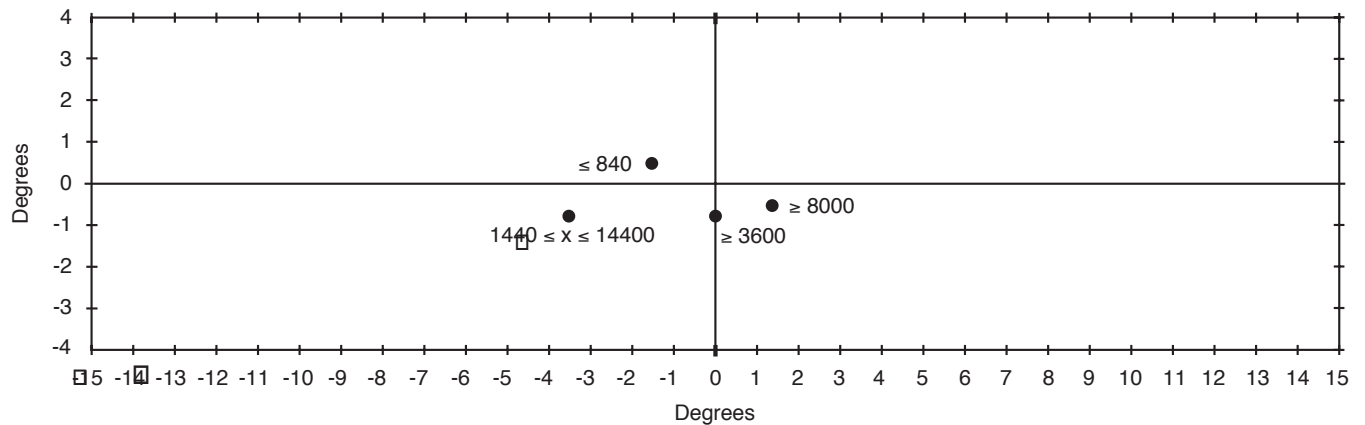


Figure 7. Four common test points. Conformity-of-production values, 12.8 V. Intensity in candela (cd). Adapted from GRE (1995).

Conclusions

From candles to high-intensity discharge, there have been tremendous changes in less than one hundred years in the light sources for vehicle headlamp systems. Materials for headlamps—metal and glass for most of that time—have given way to high-temperature durable plastics. Headlamp designs are now integrated into the vehicle styled surfaces, whereas a hundred years ago headlamps were added on the outer metal structure and looked every bit of an “ugly wart.” The visual headlamp aiming of a hundred years ago has evolved to more accurate visual/optical aiming today with the latest beam patterns. Will there be more changes and improvements? Absolutely! Light sources will continue to change. Materials will improve. Beam-pattern requirements will continue to be a compromise between providing sufficient light for the driver and limiting the light in the opposing driver’s eyes. Adaptive front lighting systems will be capable of customizing beam patterns for moment-to-moment changes in the road, driving, and weather conditions (Rumar, 1997). As vehicle manufacturers and lighting manufacturers become more international, there will be a worldwide harmonized beam pattern.

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