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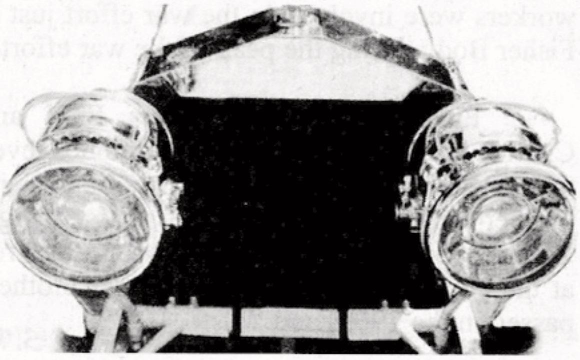


Gas Lights for Motoring

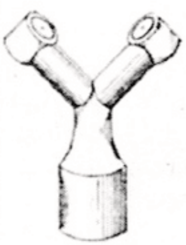
by Bouvard Hosticka

Introduction:

Riding in a car with acetylene headlamps is a treat for persons in the 21st century but was a necessity for anyone traveling by automobile at night until electric lights became common around 1913. What is a charming adventure today was a trying nuisance when it was the only means to light the way, which explains the rapid adoption of the electric lamps once viable systems became available in conjunction with electrical self starters. With electric lights, all that is needed to light up is flipping a switch rather than fussing with gas and matches. The illumination from electric lights is much better than that provided by the gas lamps even though gas lamps may have a brighter light-source than equivalent electric lamps. In modern traffic, the gas headlamps give off enough light to be seen by oncoming traffic, but the quality of the illumination is only good enough to travel at about 20 mph before over-running the beam. Given the speeds of the earlier era, and the possibility of developing night vision (something that cannot be done against modern traffic), this was good enough. The speed limit for New York in 1913 was 15 mph in towns and 30 mph on the open road, while in Virginia it was only 20 mph on the open road. Thus, for their time, acetylene headlamps were adequate and appropriate. This article explores the source of the light, the design of the lamps, and many aspects of acetylene gas including its use, generation, storage, and general safety.

Light from Lamps:

The light from a naked flame, such as used in automotive acetylene and kerosene lamps, is produced by heating carbon soot to incandescence. The soot comes from the polymerization of carbon in the lamp fuel while the heat comes from the oxidation of the hydrogen and most of the carbon in the fuel. The soot is so much an intrinsic part of lamps that it is often called lamp-black. The combustion of oil is quite complicated since it must first be vaporized, and then the many intermediate fragments produced in the process of breaking off the carbon and hydrogen from the large hydrocarbon molecules are oxidized to produce carbon dioxide and water. There is also a plethora of partial combustion products. If the combustion were ever complete leading to only CO_2 and H_2O, there would be no light or aroma associated with the lamp. The lack of an aroma (which is often caused by impurities in the fuel) would be fine, but the lack of light from a lamp is nonsense. Gases such a water vapor and CO_2 do not have the emissivity and are not opaque enough to emit light; hence the need for soot. Sootless lamp oils are fine for setting the mood in restaurants but are not up to the job of producing good illumination for the road. Literature from the era suggests a mixture of half gasoline and half motor oil as giving the brightest flame for the side and tail lights, but plain kerosene provides a good light with manageable soot. Acetylene ($HC{\equiv}CH$) is much simpler than kerosene and is already a gas when delivered to the lamp burner. The triple bond between the two carbon atoms in the acetylene makes it particularly susceptible to polymerizing, and it is a useful feed stock in plastic production. When acetylene is burned with a paucity of oxygen, some of the carbon polymerizes to pure carbon soot. This is effectively demonstrated by the black flakes formed when using a welding torch with the oxygen turned low. If all of the carbon is burned efficiently, as in an oxyacetylene torch, the flame is blue or nearly colorless. The blue light is given off by electrons recombining in the plasma of the flame and is not directly useful for illumination. A byproduct of burning acetylene or kerosene is water. This can be seen as condensation on the glass in the lamps when first lighted before they are hot enough to keep the water as a vapor. For both oil and acetylene lamps, soot and moisture are as much a part of the experience as the lovely light and the hot metal surfaces prone to singe by-standers and car covers.



A typical burner for acetylene is a Y-shaped stone with two tiny passages for the acetylene gas and other passages to entrain air and mix it with the acetylene to form two jets. The two jets collide and spread into the characteristic fan shape flame. The design of the burner prevents the actual flame from forming at the stone thus keeping the burner from clogging with soot or overheating. The burners come in various sizes to mix the proper proportions of air and acetylene and space the two jets to collide to form a flame in the most effective manner. It is not efficient to run the lamp at any flow rate other than that for which it is designed. Originally, a wide variety of burners were readily available that consume from ¼ to 1½ cubic feet per hour (cfh) of acetylene. For all sizes of burners, the gas pressure needed to produce the rated flow is about 2½ inches of water-column pressure above atmospheric. The only burners commonly available now are ¾ cfh which are too big for small lamps but running them with 0.6 cfh produces an acceptable if not ideal flame when smaller burners cannot be found. The flame will be a bit yellower and dimmer than the flame from a burner running at its design point. A larger flame does not necessarily mean a brighter lamp since much of the flame will be out of the focus area of the reflector or lens and thus will not be projected well. There is a number stamped on the burner stating its size. European burners are rated in liters per hour. There are 28 liters per cubic foot so the European sizes of 14 and 21 correspond to American sizes ½ and ¾.

When in use, the 'Y' of the burner should be oriented front-to-back to produce a flat flame parallel with the front window of the lamp. There are three primary reasons for this. 1) The flame is opaque to its own light so it is not as bright edge-on as face-on where the flame sheet is thin in the direction of the beam. 2) If the flame sheet is sideways to the reflector, the rear of the flame will be too close to the mirror at the back and might overheat it such that it melts (metal) or cracks (glass). 3) A flame sheet oriented front to back will be severely out of focus with the rear too close and the front too far from the ideal focus of the reflector or lens. Even with the flames in the proper orientation, there are problems with focus since the flame is very large, and the design of the projection optics assumes a point-source of light. Cars in movies will often have the 'Y' of the burners side to side for artistic reasons, but it is wrong. Similarly, dull metal reflectors are sometimes used to keep the glare of stage lights from the camera. Never trust theatrical productions for historical accuracy.

An efficient ¾ cfh acetylene flame will produce about 35 to 40 candle-power of light. This is a lot of light, but for reasons explained below, the beam from such a lamp is less bright than that from an electric light of 21 candle-power. A more efficient light than a naked flame can be produced by heating a mantle to incandescence with a sootless flame procured by pre-mixing the fuel with an abundance of air. The mantels start life as a cloth impregnated with exotic salts, but when first used, most of the cloth is burned away to produce a delicate lattice holding the salts. Even though a mantle heated by acetylene will give about five times as much light as a naked flame for a given fuel flow rate, they are much too fragile to survive under the vibrations of any operating car and are never used in headlights.

Lamp Optics:

There are three or four main variations of optics for gas headlamps, and it is unfortunate that there is not a consistent naming convention for them. Before describing the optics used in gas headlamps, it is useful to understand the optics of an ideal electric headlamp, and then explore how to adapt that concept to a gas light even if this approach is chronologically backwards.

The ideal electric headlamp shown in Figure 1 will have a very small filament placed at the focus of a first-surface parabolic mirror*. The focal length of this mirror is very short with the electric filament wholly contained within the reflector. Essentially all the light not given off directly in the direction of the beam will be gathered by the reflector and projected as a parallel beam.

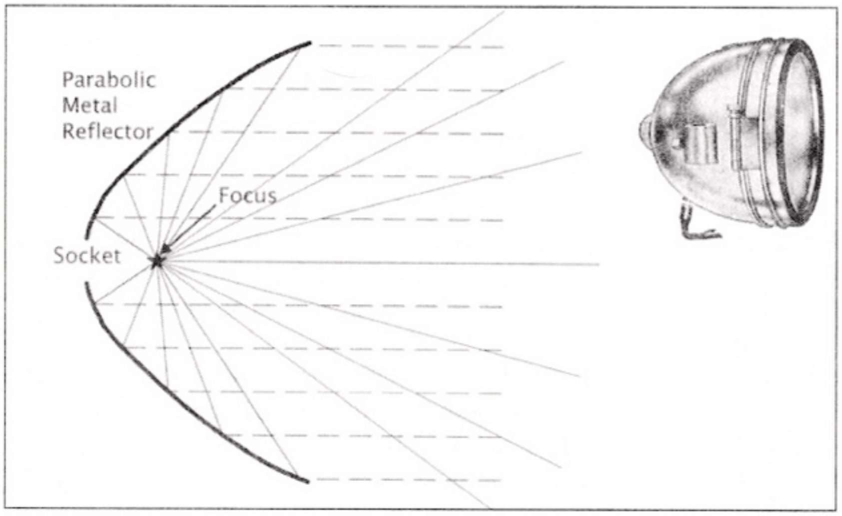


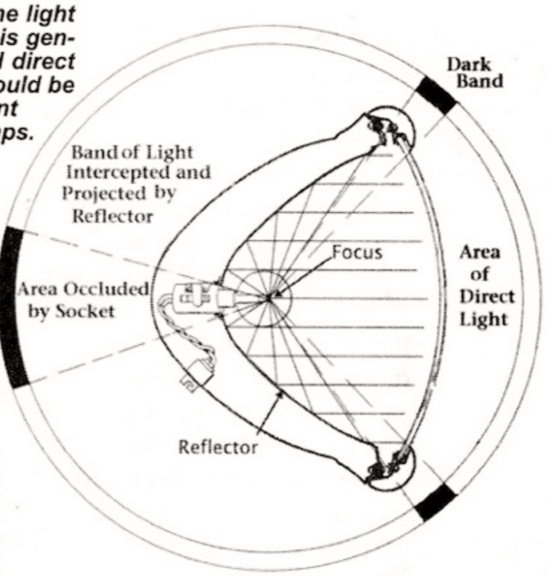
Figure 1. ***Diagrams showing the optics of an electric light. The electric filament is at the focus of a parabolic metal reflector which projects the light into a parallel beam. The convention in all diagrams is that the light is generated from a point, reflected light is indicated by dashed lines, and direct light is indicated by solid lines. There are no lines where the light would be absorbed by the interior of the lamp. Flat, segmented, or curved front windows with a uniform thickness do not affect the optics of the lamps.***

Figure 2. ***Diagram of the light intercepted and projected by the parabolic reflector as well as the light directly from the light bulb. The circle showing where light is blocked by the rim and the socket is a cross section of a sphere, and solid-angle geometry must be used to calculate the amount of light that gets out of the lamp. In this example, the socket blocks 4% of the light and the rim blocks 6%. Ninety percent of the light is directed forward,75% is focused into a beam by the parabolic reflector and 15% is unfocused. The ratio of focused light to unfocused is about 5:1.***

* Front surfaced (or first surface) mirrors do not have any glass between the reflective surface and the light. They can be either a metallic coating on the front of a piece of glass, a coating on a polished metal surface, or the polished metal itself. Second surface are the familiar mirrors that have the silvering on the back of the glass where the silvering is protected with a coat of paint.

Only a very small amount of light is intercepted by the interior of the lamp at the electrical socket and the rim of the front window as shown in Figure 2. Light directly from the filament leaves the front of the lamp in an unfocused beam superimposed on the parallel beam from the reflector. Front windows are not shown in any of the figures in this article. A window of uniform thickness, even if curved, does not affect the optics but patterned lenses are often used to help direct both the focused and unfocused part of the beam for optimal driving. The parabolic reflector in any lamp can only perfectly project a point source of light so headlamps bulbs use tightly coiled filaments to minimize the size of the light source. Tightly coiled tungsten filaments are so common now that we are surprised when we encounter the loose loops of carbon filaments that were common at the turn of the last century.

Using an enclosing parabolic reflector, as is done in the electric headlamp, cannot be done with a gas-light for several reasons. There must be a flow of air and combustion products past the flame that an enclosing reflector does not allow. The soot that is essential for a bright light along with dust in the air would quickly soil the reflector, the



moisture would corrode its surface, and the heat of the flame would melt it. Therefore; instead of a simple parabolic reflector as used in electric headlights, much more complicated optical systems are used with acetylene lamps.

The earliest automobile lights tried to come close to the simple enclosing reflector by using a polished metal reflector pierced with a large vent above the flame and a small hole for the gas burner below. A simple reflector of reasonable size would put a flame at the focus of the parabola too close to the reflector. Thus the rear most section of the reflector often does not continue the parabolic shape of the main part but is a spherical reflector imposed on the rear of the parabolic section, and the flame is set at twice the focus of the spherical section. This moves the flame far enough away from the rear of the lamp to keep it safely away from the reflector. The flame at twice the focus of the spherical section re-converges the light from the flame at the focus of the main reflector. This trick of breaking the curvature behind the flame is only practical on spun or stamped metal reflectors and is not needed with electric lamps. Although the slot above the flame permits a path for gases, the soot and wear on the polished aluminum reflector is still a constant problem. These lamps may have been adequate for the very limited use of the earliest cars but for brighter lights that were frequently used at night, betters designs were developed.

Locating the flame in a baffled and protected air-flow path well away from the reflector to protect it from the soot and heat makes for a much more durable lamp but causes much of the light from the flame to be absorbed by the interior surfaces of the lamp and not contribute to the beam. This is shown by Figure 3 in a cutaway of a typical lamp such a Solar 956A where only $^1/_3$ of the light leaves the lamp. In all cases, the flame of an acetylene lamp extends well beyond the focal point of the optics making it even less efficient than an electric light.

The Condenser-Lens lamp diagrammed in Figure 4 (*following page*) uses a spherical metal reflector located at twice the focal length behind the flame, a plano-convex lens placed directly in front of the flame with the flame at its focus, and an annular reflector. The lens suspended behind or as part of the front window makes these lamps immediately recognizable. The significance of the flame being twice the focal length from the spherical reflector is that the reflected light follows the same (but inverted) path as the direct light and is collected to form a parallel beam through the lens in the same manner as the light directly from the flame. The annular parabolic reflector intercepts light-rays that are at too large of angle to pass through the lens. The idea of a spherical reflector in combination with a parabolic reflector harkens back to the single pierced reflector described above but now the two reflectors are in two distinct parts to allow space for the flame and air currents.

The Mangin-Mirror lamp in Figure 5 (*following page*) is the simplest form of gas headlight optics. The flame is located at the focus of a Mangin mirror (sometimes called a lens mirror). The Mangin mirror is a three-element optical device combining both a pair of lenses and a mirror in one piece of glass. The two lenses are the same physical glass but the light passes through it twice so, for optical pur-

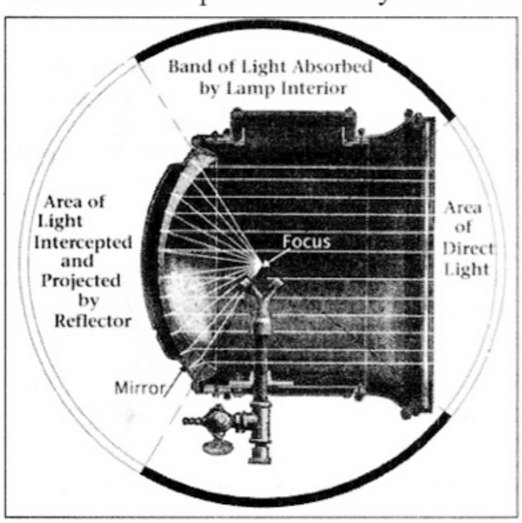


Figure 3. ***Similar diagram to that of Figure 2 but for a typical Mangin-Mirror acetylene lamp. If the light source is assumed to be a point at the focus, 66% of the light is absorbed in the interior of the lamp and only 34% is directed forward, 23% is focused into a beam by the Mangin mirror and 11% is unfocused. The flame is quite large and much of it will be out of focus so even less than 23% of the light is in the focused beam. The ratio of focused light to unfocused is at most 2:1. Note the proper orientation of the burner to form a flame sheet at right angles to the plane of the paper.***

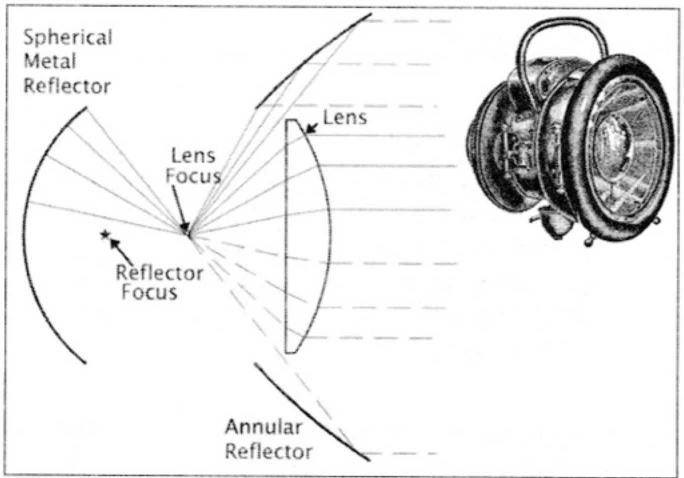


Figure 4. ***A Condenser-Lens gas light. The flame is at the 2F position rather than the focus of the spherical reflector and it is at the focus of the pano-convex lens. By being at the 2F point of the reflector, the light is reflected directly back on itself and both the reflected light and the direct light from the flame are formed into a parallel beam by the lens. To keep the lens a reasonable size, there is an annular parabolic reflector to send some of the direct rays that miss the lens into the forward beam in a manner similar to the lamp in Figure 6. Only the rays from the upper half are traced to keep the direct and reflected light paths as separated as possible in the diagram. The solid lines between the light-point and the rear reflector are BOTH direct and reflected rays. The dashed lines in the lower half are from the rear reflector. Essentially all the light from the rear reflector goes through the lens.***

poses, it is really two lenses. The resulting reflector has the identical focusing properties as a parabolic reflector, i.e. a point source of light at the focus is projected as a parallel beam. The advantages of Mangin mirrors over parabolic reflectors are that the Mangin mirror is made entirely of two simple spherical surfaces and the silvering is on the rear of the glass where it is protected from the heat, moisture, and soot of the flame. The glass itself can be cleaned without damaging the reflector. Mangin mirrors can be supplemented with a parabolic annular front reflector for better efficiency and a shallower depth of the lamp as shown in Figure 6.

The progression of styles from the Pierced-Reflector, to the Condenser-Lens, to the Mangin-Mirror and finally to the Mangin-Mirror supplemented with a reflector ring is roughly chronological.

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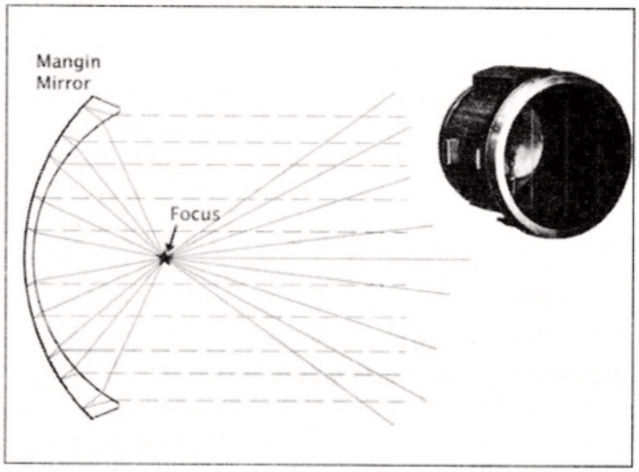

Figure 5. ***A simple Mangin-Mirror gas light. The Mangin mirror is a three element optical device where the glass acts as a lens for both the incident and reflected light from the silvering on the rear surface. The overall characteristic is to project a point of light at its focus into a parallel beam.***

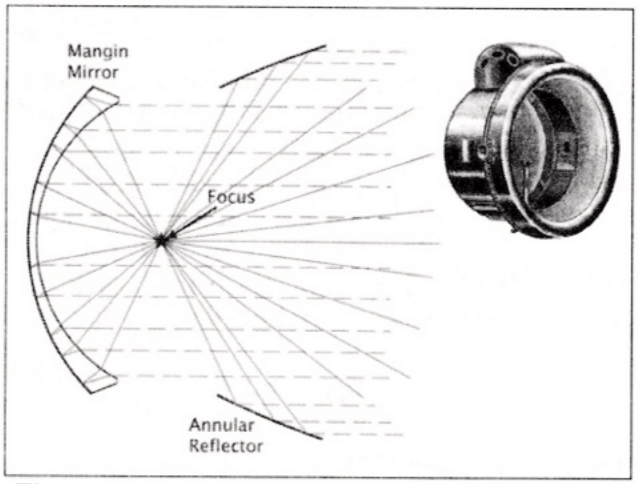

Figure 6. ***A Mangin-Mirror gas light with an annular reflector. The annular reflector intercepts some of the direct rays from the flame and directs them forward into the beam. These lamps are generally shorter than the simple Mangin-Mirror type.***

This completes Part I - an introduction to gas lights and the optics of a gas light. Next month we shall continue our look at pre-electric lighting. We will look at acetylene and some of the problems and dangers associated with the gas.