Department for Transport

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Our Ref: 429312
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Dear Mark Baker

**LED Regulation**

Thank you for taking the time to contact Secretary of State for transport about road vehicle lighting, your enquiry has been passed to International Vehicle Standards division of the Department for Transport as we lead on vehicle construction issues.

Whilst we appreciate your interest UK road safety we have reviewed your correspondence and have supplied a technical annex below but broadly we do not agree with your conclusions, to summarise.

1. In automotive applications LED light sources should not be considered in isolation. The LED's used in vehicle headlamps form part of a complex optical system.
2. European automotive headlamps have the same measured intensity requirements whether using an incandescent bulb or an LED light source.
3. There is typically a difference in colour temperature when using LED's, however the colour temperature in European headlamps must fulfil the requirements specified in the relevant United Nations Regulations.

Vehicle lighting is a complex subject and in the UK there are comprehensive suite of international regulations that define the performance of light sources, lamps and vehicle installation requirements. Furthermore, UK collision statistics do not support the suggestion that there is an underlying issue with advances in vehicle lighting technology.

Yours sincerely

International Vehicle Standards

## Technical Annex – LED light sources in automotive applications

In reality, there is no such thing as a 'point source' of light. All light sources have a physical dimension to the surfaces which emit the light. The filaments used in bulbs, upon which the regulations were developed, have a physical size and in effect are emitting cylinders. For example, the filament of an H7 bulb has dimensions of 4.1mm x 1.3mm when viewed perpendicular to the filament axis, the projection of which onto a pane normal to the axis can be considered a flat 2-D emitter in much the same way that an LED is a flat 2-D emitter. When filament lamps are scanned in order to create accurate rayfiles for simulation, a luminance camera system is used to take multiple 2-D images of the emitting filament from different viewing angles within a complete sphere. Software is then used to stitch the images together to create a 3-D model of the filament. The exact same system and process is used to create rayfile models of LEDs so, from a light source point of view, there is no difference between a filament and an LED other than the overall dimensions and the shape of the emitted wavefront of light.

The regulations are correct for historical light sources and remain correct for LEDs. Historically headlamp regulations required the lamp Illuminance to be measured in lux ($lm/m^2$) and so the primary metric for categorising headlamp bulbs was in lumens. This has since been adapted such that headlamp performance is now measured by Intensity (lm/steradian), as there is a direct relationship between intensity and illuminance based upon measured distance $I = Lux \times d^2$ (inverse-Square law); with the primary metric remaining the lumen.

A lamp designer is primarily interested in the source lumens from the LEDs/bulbs etc to determine how many light sources they require to sufficiently illuminate the road scene. It is understood by lamp designers that point light sources do not exist and the physical dimensions of the light source and its specific emitted light distribution is accounted for during the design of the lamp to ensure photometric compliance. Luminance is not the correct metric to use when determining the light source requirements to sufficiently illuminate a road scene. The luminance of a lamp, as viewed by a person outside of the vehicle, is not a measure of the luminance of the light source, but a measure of the light being emitted through the outermost optical element of the lamp design in the specific direction of the observer.

Luminance has an area dependence such that, for example, a 500 nit TV screen will have the same 'brightness' regardless of it's size, however the amount of light being emitted (lumens) will vary considerably. 500 nits does not produce the same amount of light (lumens) if the headlamps are of different sizes. Moreover, LEDs offer a small, efficient, lightweight solution to safely illuminating roads and the development of high luminance LEDs has allowed headlamp design to be reduced in size and weight. Should an artificially low luminance limit be imposed as the metric for measurement, based upon incorrect information, it will drive the size and weight of headlamps to increase. This will have a knock-on effect upon the space required to package the lights within the vehicle, adversely affecting the ability of vehicles to meet environmental targets.

It is incorrect to suggest that the light emitted from an LED does not follow an inverse square for dispersion. The Inverse-Square law applies to any wavefront of light propagating through free space regardless of the type of source. The example of a ‘point source’ is used to simplify the explanation but does not exclude non-point sources from the principle. Whereas a ‘point source’ creates a spherical wavefront of light propagating through space that can be defined using ‘simple’ maths, a source with finite size will produce a non-spherical wavefront that requires more complicated maths to define.

However, both energy wavefronts propagate outwards according to the Inverse-Square law. It is correct that the intensity from an LED will remain the same when measured at 1m or 100m, however the same is true for the intensity of light emitted from a ‘point source’. The only difference is that the intensity from a ‘point source’ is the same regardless of the measurement direction whereas the intensity emitted from an LED reduces, according to the Lambert-Cosine law, as the angle from the surface normal increases.

As previously stated the source luminance of an LED is not what observers will see when looking at a headlamp. Luminance (nits) is area dependant, 300 nits from a $1m^2$ emitter emits 1,000,000 more lumens compared to 300 nits from a $1mm^2$ surface. A standard 90mm diameter aspheric lens, as used in many headlamps, has an area of $0.0064m^2$, 300 nits ($cd/m^2$) from $0.0064m^2$ is equivalent to 1.9cd. United Nations ECE Regulation 149 requires headlamp beam patterns to have a minimum of 12100cd at the 75R test point. This would require a surface luminance from the lens of 1.9 Mnits (it is actually significantly higher than this as the 1.9 Mnits assumes the whole of the lens is emitting evenly in the required direction where in reality only a small sub-area of the lens will be directing light in the specific direction).

Meanwhile in the direction of the B50L test point (oncoming drivers eye point in UNECE regulations), the regulations allow for a maximum of 350cd, or an equivalent surface luminance of approximately 55,000 nits. If we were to limit the luminance of a headlamp within the range suggested this would be incompatible with the regulations for headlamp performance. A major compromise would have to be made on the ability of the headlamp to illuminate the road safely against the potential for glaring oncoming road users. Also, the luminance of a headlamp is based upon the light distribution emitting from the final optical element as observed by an onlooker. i.e. There is no direct link between the luminance of a light source, be it an LED, filament or gas discharge bulb, and the observed luminance of a headlamp as it depends entirely upon the design of the optical system implemented, size of the emitting lens, the efficiency of materials, thermal losses etc.

The inverse-square law of light propagation is based upon the radiant energy flux passing through/incidence upon a surface area that is normal to the direction of propagation of the light not the intensity. In photometry, the terminology for this value is Illuminance and it is measured in Lumen/$m^2$ with the SI unit of Lux (lx). Light from an LED will propagate according to the inverse square law such that the illuminance from an LED in a particular direction will reduce in proportion to the square of the distance, however, the illuminance will not be uniform in all directions. Intensity, measured in Lumen/steradian with the SI unit of Candela (cd), is independent of measurement distance and will remain the same regardless of distance. This will be the same for point sources and flat surface LEDs except that point sources will emit the same intensity in all directions whereas the intensity LEDs emit will vary according the Lambert-Cosine law and viewing angle.

There is nothing inherently unsafe about having a light distribution that is inhomogeneous provided it is controlled to avoid putting too much illuminance in the direction of oncoming drivers. Given the evidence above that Illuminance is a greater issue than luminance, it could be argued that the Lambertian emission of an LED is safer than a point source for road use. As the relative separation of approaching vehicles reduces and the viewing angle increases, a point source, emitting the same intensity as an LED along the carline axis, will be producing an Illuminance at the oncoming driver's eye that will be greater than that of the LED due to the Lambertian drop-off from the LED at the same wide angle. Again, the point is that the geometry of the source is not important when it comes to the safe dispersion characteristics of headlamps only that the emitted beam pattern from the complete headlamp should be considered.

The difference between a flat surface emitter and an idealised 'point source' is that the illuminance from a point source is uniform in all directions within a full sphere; whereas the illuminance from a flat surface LED will vary based upon the propagation angle into a hemisphere such that the illuminance reduces according to the gaussian Lambert-Cosine law as the angle from the nominal to the LED surface increases.

Nearly all modern LEDs emission is of a Lambertian form such that the Luminance (lm/sr.$m^2$)(nit) is the same from any viewing angle. The fact that an LED emission is not 'homogenous' and is of a Lambertian form is only an issue for the lamp designers whom need to account for the specific emission profile when designing the optical system. The wavefront that is observed by road users bears no relation to the emission distribution of the source LED. The optical design of the lamp will modify and reshape the LED distribution much the same as the emission distribution of a point source would be modified to concentrate/spread the light into a distribution that meets the regulatory photometric requirements.

In summary, whether a light source has a homogenous or inhomogeneous emission distribution has no effect upon the observed light distribution by other road users. We would be interested to see evidence showing that inhomogeneous light distributions can cause neurological harm, all else being equal, photons are photons, regardless of what type of source emits them. The only difference between a Lambertian and point source distribution is that the eye receives different amounts of photons from different viewing angles for a Lambertian distribution as opposed to the same number of photons irrespective of viewing angle for a point source, for which the iris response will adjust to compensate.

LEDs used in automotive headlamps are evaluated for photobiological safety against the international safety standards IEC 62471 and ANSI/IESNA RP-27. These standards identify 4 risk groups based upon exposure time for damage to occur. The majority of automotive LEDs fall under Risk Groups 0 & 1 for which no damage will occur during exposure times of up to 100s.

Some blue LEDs and the higher power white LEDs do fall into Risk Group 2 for which damage may occur for exposure times of up to 0.25s however, due to the ‘aversion response’ to bright light, no hazard is likely.

It must also be pointed out that these exposure limits are based on direct observation of the LED emitting surface at a distance of 200mm and are only of concern to lamp manufacturers who handle PCBs before they are assembled into complete lamps. In reality, in normal driving situation, no road user will ever experience this level of exposure such that headlamps equipped with the most powerful LEDs bear no photobiological risk.