New Lamps for Old, or The Magic of Light

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Talk about lamps and lanterns over a cup of coffee and somebody will moan that the back room boys have failed miserably to make any meaningful improvement within living memory. If the refreshment is alcoholic the last century, or even longer if there are veterans present and several rounds have been pulled. Looking at facts however can be much more encouraging.

Bulls eye lenses and carbon arcs or limelight must have seemed very powerful in the days of gas. The performance of the arc is still impressive and its punch outperforms nearly everything else available. However, both these lamps required generous ventilation so there was no question of enclosing the source in a wrap around reflector system to catch and focus as much as possible of the available light. Bright as they were, spotlights of the 19th and the first half of the twentieth century were inefficient because all types of light source were large and had to be kept cool.

Arc lights and the limelight give a good beam because they have high surface brightness from a very small source area. By a fundamental law of optics a focused lens or mirror aquires about the same surface brightness as the source, and this, multiplied by the area of the optical element, is the light available to project onto the stage. With a small source the beam angle is naturally small and the light from the lens much more punchy than if spread over a much larger solid angle. Consequently, from the point of view of brightness, these early spotlights were very satisfactory and could only be improved on if sources with higher intrinsic brightness can be discovered. So far, physics has found only the Xenon arc as a near equal to the carbon arc and the laser as a major improvement. The laser, of course, is unavoidably coloured and much too small to give a useful beam to illuminate actors.

Improvements must therefore be sought somewhere else. Of all the light sources discovered in the twentieth century, it is infuriating that only incandescent tungsten has enough positive attributes to be of real value for theatre. Flourescent lamps are too big and rather inconvenient to dim. Low and high pressure sodium are determinedly only available in shades of yellow and will not dim at all. The family of mercury arcs, from the old sickly green lamps that used to be used for street lighting, through the modern industrial mercury iodide equivalent, to the CSI, CID and HMI versions specifically tailored for theatre and television, all prove undimmable in theatrical terms and, although better than incandescent tungsten in terms of intrinsic brightness, still fall well below the carbon arc in this property. Theatre spotlight designers therefore have little choice and have had to learn to collaborate with the lamp manufacturers to make the best of the light that can be obtained from near-molten tungsten.

Physicists discovered long ago that the amount and colour of the light produced by a hot body can be calculated from basic equations with great accuracy. For metals and similar materials visible light output increases slowly at first as temperature is raised because most of the input energy is radiated as infra-red radiant heat. As the power input increases the body gets hotter and the redish light gets whiter and much, much brighter. If this process could be continued then a temperature of about 6000 degrees and the colour of sunlight would be optimum. Higher temperatures make the light bluer and eventually so much energy goes in the ultra-violet that the eye can no longer make any use of it. Marvelous however for getting sun burn. Unfortunately, most materials melt well below the optimum temperature and the early history of electric lighting was the story of the search for materials that would melt at as high a temperature as possible and also conduct electricity. Tungsten has been found to be the only practicable answer and this melts at about 3655K.

Comparative Source Brightness

	Candela PER SQ.CM
CANDLE	1
VACUUM LAMP	250
20 LM/WATT INCANDESCENT	1000
30 LM/WATT INCANDESCENT	1500
COMPACT SOURCE ARC	50000
CARBON ARC	70000
SUN	165000

Light Versus Life for Theatre Lamps

COLOUR TEMPERATURE	LUMEN OUTPUT	LIFE HOURS
2800K	12000	2000
3000K	20000	750
3200K	27000	150
3400K	33000	15

With the choice of material made, the next problem was how to get as close to melting point as possible without an unacceptably short life. Of course, different users had different ideas about the life they required. For the general public with no great understanding of the trade-offs involved, the longest possible life seems appropriate. But for slide and film projection and theatre, television and film stage lighting shorter lives and more light were found to be necessary. Domestic lamps operate at about 2700K, theatre lamps at 2900K, TV and film studio up to 3200K and the very short life photo-flood at 3350. The table shows how luminous efficacy – lumens per watt – increases as operating temperature is raised and life decreases.

Several tricks have been discovered to improve life. Filaments fail for complex reasons but the most important is that the metal evaporates and this happens with increasing rapidity as the temperature increases. Hence, as a lamp gets older, there is less and less metal on the filament and if this does not happen evenly, one point will