Chapter 6

NON-INCANDESCENT LIGHT SOURCES ON STAGE

There are a number of ways of calculating the theoretical number of lumens that could be obtained by the perfect conversion of a watt of electricity into light. One such calculation puts the amount at 673 lumens per watt. Other calculations go as high as 692 lm/watt. (Note that the energy in a lumen is dependent on the wave length of the light being examined.) Whatever the figure, it dwarfs the best of incandescent lamps which produce less than thirty lumens of visible light per watt. Outside of the theatre, modern energy saving approaches to lighting have resulted in tremendous savings in energy costs and effect on the environment. The stage, however, lags far behind, mostly because it remains committed to the concentrated filament incandescent lamp which is easy and safe to use and can be dimmed by relatively simple electronic equipment with only minor color shift problems. Also the theatre has a huge investment in equipment designed around the incandescent lamp.

Incandescent lamps are very poor at converting electrical energy into visible light.

The incandescent lamp's inefficiency, which results in most of the energy it consumes being converted into heat, costs the theatre double; once for the power to operate the lamps and again for the extra air conditioning needed to remove the excess heat from the building. The heat also is destructive to color media and equipment. Additionally, it is a constant annoyance to actors, singers and anyone on stage.

The incandescent lamp is a very poor source of cool colors, particularly pure blue. This increases lamp and power costs because much more power is needed to produce usable quantities of blue light. Moreover, while the concentrated filament is a reasonably small source, it is still far from a theoretical point, particularly in large wattage lamps which must have larger filaments. This makes collection of its light difficult and inefficient.

Incandescent lamps are inefficient in the production of blue light

For the above reasons, there is great pressure on the theatre to move to a more efficient light source. In Europe, where cost of electrical current is several times what it is in the USA, major theatres have long since given up incandescent lighting of cycloramas (one of the biggest power loads in the theatre) in favor of fluorescent lamps which are much more efficient than incandescents, particularly in the cool-light range.

Ironically, the European standard voltage (220-240 vac) makes their incandescent lamps even more inefficient than ours. It is more difficult to make a compact concentrated filament when the filament wire is half the diameter or twice as long as that in a 120 v lamp. This problem is so acute that many theatres use step-down transformers to enable them to operate luminaires at 120 v. These transformers also use some power and add huge amounts of weight to the rigging system (they are installed at the luminaires to avoid voltage drop.).

Clearly there is a real need for a better point source of light for the theatre. This need is being met by gaseous discharge lamps.

Gaseous Discharge Lamps

Ionizing gases causes them to emit light.

It has long been known that any gas which is ionized by electrical current, will emit radiant energy, usually much of it in the visible range. This phenomenon is found in nature in the northern lights and can be easily reproduced on a small scale by enclosing any gas or combination of gases in a glass tube equipped with electrodes and applying sufficient voltage to cause current to flow through the gas. The result will be a glow of wave length(s) typical for the gas(es) used. A spectroanalysis of this light will reveal that it is made up of narrow lines representing individual or closely spaced groups of wavelengths with darkness between—a line spectrum.

Starter and ballast

The practical requirements for making light by gaseous discharge are quite different from those for operating an incandescent lamp. First, the gas must be completely enclosed in the tube, not polluted by air or any other unintended gases. Electrodes must be installed at the ends of the tube and carefully sealed to prevent either the escape of the interior gas or the intrusion of air. If the gas is at relatively low pressure and the tube is long, considerable voltage will be needed to start the flow of electrical current. However, once the flow begins, the resistance of the ionized gas drops to near zero and some outside means must be used to control the amount of current that flows. These requirements mean that, compared to the incandescent lamp, operating a gaseous discharge lamp requires special equipment. Usually a *starter* is needed to provide the pulse of high voltage needed to ionize the gas and a *ballast* is needed to control the flow of current, once started. These items add to the cost of luminaires using a gaseous sources and also consume current, reducing overall efficiency.

Long-arc and short-arc lamps

Despite these complications, gaseous sources have proved efficient and economical. They are widely used for general illumination and, more recently, as stage lighting sources. Two general types of gaseous discharge lamps are presently in use: *long-arc lamps* which include fluorescent lamps and a variety of general illumination sources such as street lighting lamps, and *short-arc lamps*, which qualify as point sources.

Fluorescent Lamps on Stage

Although they are basically long-arc gaseous discharge lamps, fluorescent lamps are a special category because of their complicated energy conversion process. They are found in almost every architectural lighting situation requiring a high level of illumination at reduced cost of operation but find only limited use on stage, mainly as cyclorama lighting. This is because they cannot be made into a point source.

The operation of the fluorescent lamp involves two energy conversions: first from electrical current to ultraviolet light and then from ultraviolet light to visible light. Both of these steps are much more efficient than the conversions performed by an incandescent lamp (current-heat-light) and despite the need for an energy consuming ballast, the overall result is a source which is as much as 3-4 times as efficient as an incandescent lamp. They work as follows:

Two-step energy conversion

1. The inside of the fluorescent tube consists of a long-arc gaseous lamp using mercury vapor as the gas. Pressure and temperature range are adjusted so that maximum energy from the current passed through the tube is converted into the ultraviolet lines of the mercury line spectrum. This conversion is based on quantum theory: Atoms of the gas are driven to a higher than normal level of energy by the electrical current. When the atoms return to their normal energy level, each one releases a photon. These photons make up the UV light generated inside of the tube. Only a minimum of energy is converted into visible (purple) light. The UV light lies in the middle and far areas of the UV spectrum and could be potentially dangerous, therefore none of it is allowed to escape the tube. This is accomplished by using glass for the tubes that is opaque to the dangerous wave lengths.

The mercury-arc

2. The UV light produced as above is absorbed by phosphors bonded to the inside of the tube. Phosphors are chemicals that can absorb UV energy and emit visible light. This conversion is known as fluorescence, hence the name of the lamps. The visible light emitted is mostly in the form of continuous-band spectra. Each band includes only a part of the total visible spectrum, therefore to produce a normal looking light several different phosphors are mixed to additively produce the sensation of white light (see Chapter 9 for details about color mixing). This visible light is transmitted through the glass of the tube and is the light output of the lamp. Note that little heat is produced in this process.

Phosphors are activated by the UV light—fluorescence.

Advantages of the fluorescent source are:

- high efficiency;
- low heat output;
- good color rendition (if proper blend of phosphors is used);
- efficient in blue range;
- long lamp life.

Disadvantages are:

- usable as flood source only;
- deficient in red-yellow range;
- may flicker on start-up unless special equipment is installed;

- failure of lamp or auxiliary equipment may result in flickering instead of a simple outage.

Although European theatres, particularly large opera houses have consistently installed single-color fluorescent lighting to produce daylight effects on cycloramas saving very significant amounts of electrical costs, this practice has not caught on in the U.S. However a more flexible possibility now exists: the use of fluorescent three-color primary cyclorama lighting. Just as three-color incandescent cyc lighting requires three sets of circuits and controls (sometimes four if the blue circuit is doubled), three-color primary fluorescent cyc lighting will require three circuits and three dimmer ways. Such systems have found some acceptance in television studios where lighting loads tend to be very heavy and where air conditioning loads (much increased by waste heat from incandescent lamps) can mount up to a huge expense. The lamps used for this purpose are fluorescent tubes equipped with special phosphors (and sometimes also filters) that produce only red, green or blue visible light instead of a mixture. Electrically they are the same as normal tubes.

It seems obvious that, as the pressure for greater efficiency and better energy conservation grows, the use of fluorescent cyclorama lighting will increase.

Ultraviolet Sources for the Stage

Fluorescent tubes can be designed to produce large amounts of ultraviolet light by altering the phosphors. This light can be used to cause a wide variety of materials to fluoresce, although in many cases with limited efficiency. Some of these fluorescent materials are made up into stage paints, makeup, crayons, and treated fabrics. Spectacular transformation effects can be created by painting or drawing on scenic elements which can have two radically different appearances depending on whether they are viewed by ordinary light or ultraviolet light. The light that activates these effects is "UVA" or "near UV" light, commonly called "black light."

Several commercial suppliers offer to make up drops up to full stage sizes that can be transformed by shifting from white light to black light. Those wishing to prepare their own effects will find several sources of paint and related products.

There are three light sources commonly used to activate black light pigments:

- black light fluorescent tubes
- mercury vapor lamps
- HID source follow spotlights

Three-step energy conversion

All of these sources produce visible light in varying amounts which must be filtered away if the effect of the fluorescent pigments is to be seen. The fluorescent UV process is unique in that its use involves a three-step energy conversion process:

1. Energy from electrical current is converted into far and middle UV light inside a standard fluorescent tube. Note that the tube glass is specially formulated to contain the potentially dangerous UVB and UVC.

2. This UV is then converted into near-UV by the special phosphors bonded to the inside of the tube.
3. This near-UV (black light) passes through the tube and is used to illuminate the specially painted scenery, makeup, fabrics etc. where other phosphors make a third conversion into visible light, usually in narrow bands of color producing striking effects.

Black light fluorescent tubes are electrically the same as regular tubes of the same size, bulb configuration, and wattage. They can be dimmed by any dimmer rated for fluorescent lamp dimming and can be operated in any luminaire designed for fluorescent lamps. However, luminaires equipped with polished metal reflectors are more efficient than those with white enameled reflectors.

Filtering unwanted light

Black light fluorescent tubes produce a considerable amount of visible light, mostly in the violet range which must be filtered out to make the fluorescent effects visible. Some tubes may be purchased already equipped with filters, tubular filters can be separately purchased and installed, or filters may be installed at the front of the luminaire. Note that some theatrical color media in the amber range will serve as emergency filters for this purpose.

Flooding the stage with black light

If an entire stage must be illuminated with UV light, fluorescent tubes are by far the most efficient and economical method. However if a defined pool of UV light is needed, fluorescent UV will not work. Mercury vapor lamps in a PAR-spot configuration offer a possible solution. They produce a fairly well-defined pool of UV that tapers off into darkness over a considerable distance. They also produce some spill. Therefore, if a tight spotlight effect is needed, they are best operated in a PAR can or a funnel-type housing that cuts off the spill and the outer part of the beam. Like all gaseous discharge lamps, these must be operated with a ballast to control current flow. Because these lamps also produce a large amount of cold-blue visible light, they must be operated with a special filter that blocks the visible light and transmits the UV. This filter will run hot; it must absorb all of the energy in the visible range. Units that include the ballast and a housing for the lamp are available, made for the landscape illumination market where the cold blue-green light is used because it flatters foliage at night. UV filters are available for these fixtures and funnels can be devised.

Producing a defined pool of black light

Mercury UV lamps delay starting for a period of time after the current is applied and then come on gradually and unevenly; fluorescent lamps sometimes flicker on starting. Thus the best way to use either type on stage is to turn them on and let them warm up before the curtain goes up. Any moderate-to-high level of stage lighting will obliterate the fluorescence they cause, masking their presence until the visible light is dimmed. Then the UV scene will appear, almost as if by magic. The fluorescent scene can be ended simply by bringing back the visible light. Note that mercury UV lamps should not be turned off until they are no longer needed. Once heated up, they must cool down before they can be reliably started again. This may take as long as twenty minutes.

Lamps will not start when hot

If a pool of UV must follow the action of the play and/or must be sharply defined, the best solution is a follow spotlight that has a UV producing source and a filter to cut off the visible light. Modern follow spot-

Black light follow spotlight

lights, with the exception of small incandescent-source types, are powered by high intensity discharge (HID) lamps (discussed in detail below). In addition to visible light, these lamps produce radiation throughout the UV range including near-UV. Normally the lens glass for these luminaires is chosen to block UVB and UVC and may also block some of the UVA. Nevertheless enough will usually remain to create very effective black light spotlighting. A special filter will be needed that blocks visible light but passes UVA.

Other Long-Arc Sources

Although the fluorescent lamp has found considerable use on stage, other long-arc sources have not. Such sources include neon signs, sodium vapor lamps, mercury vapor lamps, and a number of more exotic types used for scientific experimentation. The efficiency of these lamps has, however, led to their use in a variety of lighting situations such as street lighting and the illumination of large spaces such as warehouses. Those most commonly in use are sodium vapor lamps (pure yellow light), high pressure sodium vapor lamps (pinkish-yellow), mercury vapor (cold, often greenish, white), and long-arc xenon (cool white). These sources almost never appear on stage unless there is a need to introduce this particular light as a plot requirement.

Short-Arc High Intensity Discharge Lamps—HID Lamps

High intensity discharge lamps are short-arc lamps. Their arc is confined to a very small space in a compact-arc tube instead of being extended such as the arc in a neon tube or a fluorescent lamp. The basic structure of these lamps (Figure 6.1) consists of a relatively small tube of quartz, fitted with two electrodes with a small gap between them. The tube, filled with whatever gas or gases are desired, operates at high pressure and temperature, therefore it is further enclosed in an outer glass envelope.

Pulse starting

Starting is usually accomplished by sending a short but very high voltage pulse through the lamp which ionizes the starter gas, usually argon. Once the arc has started to flow through the argon, the other elements are heated and become the main light source in the arc. Once started and heated up, most HID lamps must cool after being shut off before they will restart.

High pressure mercury lamp

Hazards of xenon lamps

The earliest HID lamp that came into common use was the high pressure mercury vapor lamp. While very efficient, its color made it useless for stage use. The first lamp adaptable to the stage was the xenon lamp which produces a cool white light. It soon found use as a source for both scenic and motion picture projection. Early lamps were dangerous, particularly in larger wattages. They emitted dangerous amounts of far- and middle-UV light which in addition to being dangerous itself, caused part of the oxygen in the air surrounding the lamp to be converted into ozone, a poisonous gas. The lamps themselves operated at very high pressure, as much as 40 atmospheres which made them explosive. Xenon lamps are still in use and still dangerous, although they have been "tamed" somewhat. Ozone-free varieties are available and research has reduced the possibility that the glass envelope will suddenly fail ("devitrify" in the euphemistic language of the engineers), throwing fragments of glass around at the speed of a pistol bullet. Their use on stage is becoming increasingly rare because there are safer substitutes (metal halide lamps), although the highest powered scenic projectors and follow spotlights may still utilize them

The category, HID lamps, still includes both the xenon and high pressure mercury vapor lamps but now also encompasses a large and fast growing family of metal halide lamps. Electrically these lamps are similar to mercury vapor lamps, indeed their basic fill is mercury with argon added as a starter. However the essential part of the fill is a carefully measured "dose" of metal halides, usually iodides of metals chosen for their efficiency and color of radiation in the visible spectrum. The result is a very complicated line spectrum displaying all of the various spectral lines of the elements in the arc.

Metal halide lamps

Metal halide lamps produce light that is essentially white to the eye although it is made up of a complex mixture of spectra from the various metals introduced into the arc plus the basic spectra of mercury and argon. This light is described by means of a *correlated color temperature rating*—a way of describing the apparent color temperature of non-incandescent sources whose spectra are made up of lines and/or, in some cases, bands of color. It is specified by citing the kelvin temperature of a true incandescent source which produces the same visual effect as that of the mixture of line spectra. Some of the characteristic of metal halide lamps are:

Correlated color temperature rating

- high efficiency
- produce essentially white light described in terms of correlated color temperature
- relatively long life
- can serve as a point source for use with lenses and precision reflectors
- high gas pressure inside bulb—may be dangerous
- most are not electrically dimmable
- many produce dangerous UV radiation
- most have limited operating positions
- need auxiliary equipment
- most cannot be immediately restarted after being shut down.

Halide lamps are made in a wide variety of types and sizes and find use in many applications outside of the theatre because of their efficiency, long life, and good color rendering properties. Most of these general service HID lamps will not work well with lenses or precision reflectors, however a few are made especially for use in precision optical equipment, including sophisticated modern theatrical luminaires. They are practically the only lamp used in modern automated luminaires with high light output ratings and are finding their way into top-of-the-line non-automated luminaires.

Dangers of metal halide lamps

Metal halide lamps normally are made with a double envelope. The outer glass envelope serves to stabilize the temperature of the inner-arc tube and to at least partially contain dangerous radiation. Although the lamp will operate with the outer envelope broken, this is exceedingly dangerous. When an outer envelope is broken, the lamp should be immediately shut off. Indeed, many types of lamps are equipped to self-extinguish within fifteen minutes of failure of the outer envelope.

The inner envelope is the *arc tube*. It is normally made of quartz and operates at high pressure (up to 50 p.s.i.) and temperatures as high as 1800° F (1000° C). If this tube is broken while the lamp is at operating temperature, hot particles of quartz may be thrown around at high velocity. The lamps must therefore be operated only in an enclosure capable of controlling such an explosion without allowing any fragments of quartz to escape.

Explosion danger

In addition to the hazards from high pressure, the lamp, even with the outer envelope intact, radiates dangerous quantities of middle- and far- UV which can cause serious skin burns, eye damage and even cancer. Therefore the housing should contain the unfiltered light from the lamp allowing only safe light to be emitted. Either the lens must be made of special UV-blocking glass or a special UV filter must be installed. Clearly, halide lamps should be operated only in an approved, enclosed fixture designed for this purpose.

Handling precautions

Halide lamps should be handled only with cotton gloved hands to avoid any fingerprints, grease or oils getting on their outer surface. If they do become soiled, they must be carefully cleaned with alcohol. Used lamps should be disposed of following the manufacturer's instructions, not simply thrown into the trash.

Operating Conditions

All HID lamps, including metal halide types require special ballast equipment to control the flow of current through them. Unlike an incandescent lamp, whose resistance increases as the filament heats up, gaseous discharge lamps have a "negative resistance characteristic." This means that as the arc is developed through the gaseous medium in the arc tube, the resistance drops precipitously, approaching zero. Thus, as the lamp "fires" it becomes a short circuit in the system. To prevent it from destroying itself and parts of the electrical supply system, an external current limiting device known as a ballast must be inserted in series with the arc. Such ballasts must be designed to fit the current carrying characteristics of the variety of lamp being used. Therefore lamps are listed in catalogues with the proper ballast specified. Use of an improper ballast can result in early lamps failure or even in the explosive destruction of the lamp. *HID lamps are not interchangeable, in the same way incandescent lamps* are.

Lamps must be operated with the proper ballast

Most HID lamps, including the metal halide varieties, have limited operating positions. These are determined by the internal structure of the lamp and cannot be ignored without severely shortening the life of the lamp. This is one of the reasons that many automated luminaires are built to be mounted in a horizontal position and the beam directed toward the stage by a moveable mirror. A few metal halide lamps are listed as "universal burn" and can be mounted in any position and/or moved to any position as the luminaire is angled.

Operating position limitations

Compared to even the best tungsten halogen incandescent lamps, metal halide lamps are phenomenally efficient. For example, a number of commonly used 250 watt metal halide lamps are rated at an initial output of 20,000 lumens and mean lumens at 15,500. Commonly used 250 watt T-H lamps are rated at 4800-5000 lumens. There is also a huge difference in rated life. Halide lamps are rated at 8-10,000 hours compared to T-H lamps whose life ratings are in the vicinity of 250 hours. However it must be noted that the long life of the halide lamps decreases significantly if the lamps are repeatedly shut off and restarted instead of being run continuously.

Best life expectancy when run continuously

Applications of Halide Lamps

Engineering and safety restrictions make it unsafe to simply install a metal halide lamp in a luminaire originally designed for a T-H lamp. New types of luminaires are, however being made to satisfy the requirements for using HID lamps. For instance, almost all automated luminaires except those of the lowest power, utilize HID lamps. Also, fresnel and ellipsoidal luminaires are presently being manufactured which are designed to operate with metal halide lamps. These powerful luminaires are currently in use in the film industry where their high price can be justified. It is almost inevitable that these fixtures will enter the theatre service as they become more economical. And, as already noted, modern follow spotlights, again excepting those of lowest power, utilize HID sources.