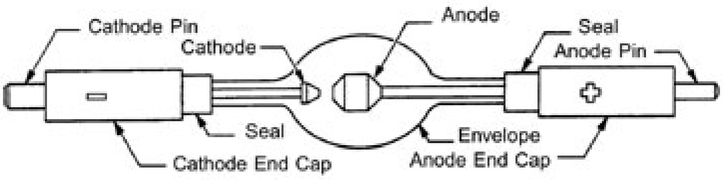
Everything you wanted to know about xenon bulbs

I am sure that most theatre managers and owners at one time or another have questioned why a xenon bulb costs so damn much money. It’s a question that I think we have all asked, but probably never received a good answer to. It’s hard to believe that you have a choice between buying a decent used car and a light bulb for the same amount of money. But there is a major difference — the used car won’t put enough light through your projector to even see the credits!

First of all, let’s start pronouncing it right. The word is "xenon", pronounced zee-non, not x-enon or z-on, Xenon is a rare gas derived during the production of liquid oxygen. Is it expensive? Yes, compared to oxygen and some other common gases such as argon and helium. The reason for the expense of the gas is the small amount of it that is contained in the atmosphere and the purity of the gas which bulb manufacturers require. Most manufacturers buy xenon, certified to be 99.9995% pure in order to minimize sources of possible contamination in the bulb.

Why do they use xenon? The reason is simple: xenon at elevated temperatures most closely matches the desired color temperature of daylight (6000 degrees Kelvin). The result of this is blue sky in an outdoor scene on your theatre screen.



If it’s a light bulb, where’s the filament? There isn’t one to be exact. A xenon bulb such as the one you use in your lamphouse is a compact arc discharge lamp that contains two electrodes, an anode and a cathode. It’s kind of like encapsulating your positive and negative carbon in a quartz envelope, but with one major exception. You don’t have to change the electrodes, because they are nonconsumable. That’s another reason we use xenon; it’s an inert or noble gas with a very low reaction rate.

The big electrode in the bulb is called an anode and is made of pure tungsten. This is the electrode that glows so brightly when you view it through the bulb observation window of your lamphouse, But don’t be deceived by its glow, because it provides no light at all through the lamphouse’s optical system. The reason that it is so big and glows so brightly is that it is being bombarded by electrons from the cathode or smaller electrode. That also helps to explain why it is made of tungsten. The surface temperature at the face of the anode (closest to the are) is over 2000 degrees centigrade and tungsten, being a refractory metal, has a liquidous temperature of almost 3000 degrees Centigrade. If a manufacturer were to use stainless steel or aluminum for an anode, it would simply melt away in less than a minute.

The smaller, pointed electrode is called a cathode. This electrode is also made of tungsten but with a slight twist. The tungsten is doped with thorium which lowers the work function of the electrode and provides more free electrons into the area. The thoriated tungsten also facilitates easier starting of the bulb just as thoriated welding electrodes start easier than non-thoriated ones. The cathode, while you can’t see it with the naked eye, provides the light for the optical system of your lamphouse.

Tungsten, itself, isn’t found in your everyday rock, and as with xenon, bulb manufacturers insist on extremely pure tungsten to minimise possible bulb contamination. Pure tungsten, such as the anode material, is extremely difficult to machine and requires expensive ceramic tool bits and lots of time in machining. The cathode electrode requires the same tool bits but is much easier to machine because it is thoriated tungsten. In most circumstances, the electrode heads are press-fit or brazed onto an electrode shaft to reduce material costs. The shaft material on the anode electrode must still be tungsten due to the elevated temperatures which the anode operates. However, the cathode electrode shaft is often molybdenum, which, while it is still a refractory metal, it is much less expensive.

The envelope surrounding the electrodes and containing the xenon gas is made of quartz. As with everything else in the bulb, temperature once again enters the picture. The temperature of the quartz envelope is between 600 and 700 degrees centigrade during bulb operation. If one were to use regular glass, you would have a molten mess within a few minutes of operation.

What's this ozone stuff? Well, it’s really quite simple. Ozone is actually O_3 which is an extra oxygen molecule. A xenon bulb is capable of producing O_3 if the quartz envelope allows light transmission in the 180 nanometer level. Early xenon bulbs allowed this phenomenon to occur. In certain circumstances, based upon the application, ozone generation is desirable. But the projection booth is not one of those applications. Henceforth, the development of "ozone-free" quartz. Ozone-free quartz is quartz that is doped with titanium in the ingot stage of manufacturing. This doping acts as a shield and blocks light transmission below 220 nonometers. The resultant is no ozone generation during bulb operation.

Now that we’ve discussed the key components of the xenon bulb, we have to put them all together to make it work.

First we have to make the envelope. This is done on a large lathe using extremely hot flames of either hydrogen or propane and oxygen. While a piece of quartz tube is inserted and turning in the lathe, it is heated to a near molten point, and a glass blower blows into the inside of the tube to form the desired envelope. They all end up looking the same because the glass blower uses a carbon paddle as a guide or template when blowing. You can always tell the glass blower in a xenon bulb plant, as he’s the one with the year-round suntan or burn. Glass blowers in a xenon bulb plant make pretty good money and rightfully so. The molten or working temperature of quartz is around 1400 degrees centigrade, and the glass blower sits only a foot or so away while making the envelope.

After the envelope is made, it is usually cleaned in a bath of hydroflouric acid which is real potent stuff and can actually dissolve quartz if it is left in an undiluted mixture long enough. Now you have to put the fill tube on the envelope. This is the dimple looking thing that you see on the anode side of your bulb’s envelope. It’s put on that side to keep it out of the path of the light. The hole for the fill tube is either blown or drilled in the envelope by the glass blower and then a smaller piece of tubing is fused to the envelope using a smaller hand torch.

The electrodes go through quite an ordeal themselves after machining. First they are ultrasonically cleaned and de-greased to remove any machine lubricants. Then the anode electrodes are heated in a vacuum chamber to around 2400 degrees centigrade and stay at that temperature for several hours. The reason for this is to pump out those contaminants that would otherwise outgas or evolve during bulb operation. The cathode electrode is also heated in a vacuum chamber both for cleaning and for thoria activation. The thoria activation is accomplished by elevating the electrode temperature for a short period of time. This causes the thorium to migrate, or move, to the cathode surface.

After the electrodes are allowed to cool, they must next be assembled into a seal assembly. If the bulb wasn’t sealed, that expensive xenon would escape and our shiny, expensive electrodes would turn blue and green. There are three basic seals employed by the various bulb manufacturers in the world; the graded glass seal, the molybdenum cup seal, and the molybdenum ribbon seal. Each manufacturer will tell you that their seal method is the best, but the truth is that they're all good if done properly.

A graded glass seal is performed directly onto the electrode shaft, and as the name implies, requires various grades of glass. You can't attach quartz directly to a tungsten or molybdenum shaft due to the the drastic difference in their expansion rates while under heat. Therefore, a glass bead is first formed around the electrode shaft and then a glass of higher temperature is placed on top of it and another on top of that until you build it up to quartz. Once the seal is built up to quartz, it may be directly sealed to the quartz side arm of the envelope assembly using a torch.

The molybdenum cup seal is also sometimes referred to as a "housekeeper seal" and as the name implies, utilises a cup or thimble-looking part called a moly cup. Quartz will seal to very thin molybdenum and the moly cup's edge is chemically or electrochemically etched down to a thickness of .0015 of an inch. Using a torch, the quartz is compression scaled to the moly cup's edge while it is turning in a lathe under a vacuum. The vacuum is required to prevent oxidation of the molybdenum and it makes the molten quartz collapse around the cup's edge providing a quartz-to-metal seal. The electrode shaft is then brazed to the moly cup, completing the seal. A ribbon or foil is used. This ribbon is also etched down on the edges and is usually spotwelded or brazed to the electrode shaft, The complete assembly is then sealed to a quartz tube or side arm in a lathe while under vacuum.

All quartz work utilising heat on the bulb is performed while the bulb and electrodes are under vacuum. Once the parts are put inside the envelope assembly, the bulb is attached to a vacuum station by means of the fill tube and the complete assembly has a vacuum drawn on it. The bulb assembly is then placed on another lathe and the side arms are shrunk down on the electrode shafts.

This is done to insure some form of mechanical integrity during handling and shipment of the bulb.

The electrode spacing must next be set. The amount of gas pressure and the distance between the electrodes determines the voltage that the bulb operates at during operation. The spacing is set on a lathe on graded glass and moly cup seal lamps, and is usually set by hand by a spacer on ribbon seal lamps. Most manufacturers usually hold the spacing tolerance on a theatre xenon bulb to plus or minus .010 of an inch during manufacturing.

Now that we've subjected this xenon bulb to all this heat, let's subject it to a little more. Quartz, being a member of the silica family, is very susceptible to strain patterns, especially after all that heat we've subjected it to. If we don't want our bulb to explode right after we've turned it on, we've got to get rid of those strain patterns. This is accomplished by heating the bulb assembly to 2100 degrees fahrenheit and then gradually bringing it back down to approximately 1200 degrees fahrenheit on a timed temperature slope. Most manufacturers also pump a vacuum on the bulb during this operation to remove those unwanted contaminants.

Finally, now we get to the fun part. The bulb is a xenon bulb and it's only right that we put some xenon gas in it. Using sophisticated measuring equipment, the bulb is again subjected to a vacuum of approximately 10 to the minus B. This means one part per million of contaminates for us commom people. Then the vacuum system is shut off and using precision measuring equipment, the bulb is pressurised to approximately 70 p.s.i. absolute pressure. Here again, for us common folk, that's approximately four times the pressure of the air we breathe.

One thing has always bothered me. Nobody ever asks how you get the bulb off of the fill station! If quartz collapses when heated under a vacuum, it only stands to reason that it expands when heated under pressure. If you placed a torch on the fill tube after filling a xenon bulb, it would blow out and that expensive xenon would escape. Somehow that positive xenon pressure has to be reduced to that of a vacuum, so that the quartz will collapse like it did when we made the cup seal. This is accomplished by placing a cup of liquid nitrogen under the pressurized xenon bulb. The liquid nitrogen freezes the xenon in the bulb forming a "little pile of snow" in the bottom of the bulb. Therefore, we’ve taken a pressurised gas and formed an unpressurised solid and in turn, a vacuum, because the only gas in the bulb was xenon. A torch is now used to remove the bulb from the fill station by heating the fill tube close to the envelope. Once the bulb is removed from the liquid nitrogen, the solid xenon heats up and returns to a pressurised gas. Alas, the birth of that expensive xenon bulb!

Wait a minute — we’re not done yet! It seems that all lamphouse manufacturers design their systems to utilize different bulbs. This is done to insure your bulb business, because the lamphouse is the razor and the bulb is the blade, which requires periodic replacement. A 2000 watt bulb is a 2000 watt bulb, right? Yes, to an extent. But how that bulb is connected to a lamphouse varies from manufacturer to manufacturer. The final step in making the bulb is the end fitting or end ferrule configuration. The installation of these fittings is quite critical as it affects the overall focus of the bulb in the lamphouse. This operation, typically called basing or mounting, is accomplished on precision mechanical machinery utilising optical comparitors and microscopes. Most manufacturers maintain plus or minus .010 of an inch on end fitting installation to guarantee repeatability in configuration.

Well, what’s left? How about a little testing and quality control? I know it’s hard for the guy who puts the bulb in the lamphouse and it doesn’t work to believe, but I really believe that all manufacturers do test their bulbs. Most manufacturers even run them for a considerable amount of time to eliminate premature failures in the field. The bulb is tested in a lamphouse or burn-in fixture to ascertain that it meets the industry standards for voltage and amperage. Some manufacturers even spot-check their bulbs to determine lumen or light output. Last, but not least, enters the quality control inspector who checks the operational, mechanical, and optical quality of the bulb. Once his eagle eye has analysed the product and the documentation associated with it, the bulb finally goes to packaging for encasement in its "tomb" until you unpack it to install in your lamphouse on a Friday night with people screaming, "WE WANT A SHOW!".