Reflection and Refraction

What is **REFRACTION**?

def: REFRACTION is the bending of light rays caused by their passing through a surface separating a medium of one OPTICAL DENSITY from a medium of a different optical density.

Important information for understanding refraction:

Speed of light in a vacuum = 186,000 miles/second - the ultimate speed limit.

(this is a theoretical value)

Light travels in a straight line.

def: **MEDIUM** a material that will transmit light.

def: **OPTICAL DENSITY** refers indirectly to the speed of light in a mediumor, how fast light travels through a medium.

def: **INDEX OF REFRACTION** - a number which refers to the optical density of the media that light passes through. It is always greater than 1.000 (1.000 is that perfect vacuum)

The higher the index of refraction, the more light slows down. Ex. glass index is 1.51 - 1.89, water 1.33,diamond 2.42def: **NORMAL** - a normal is an imaginary line perpendicular to the surface at the point of incidence.

From low optical density to higher optical density, the light will bend towards the normal.

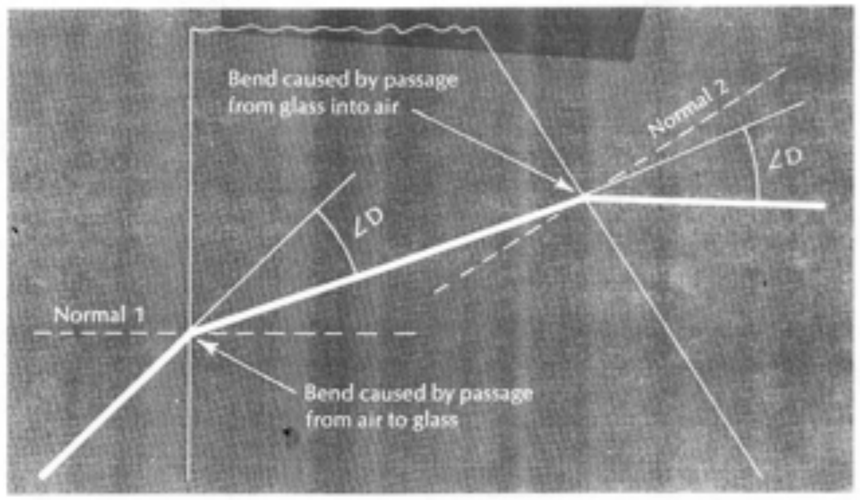
From high optical density to lower optical density, the light will bend away from the normal.

Refraction is uniform and differential. - this means different wavelengths will bend at different rates (because they have different energies) but the bending for a given energy, at a given ratio of indices. This differential quality leads to a “rainbow at the edge of sharply focused lights with lenses. This is called chromatic abberation.

3 factors determine the amount of bending that can take place:

1) the ratio between the indices of refraction
2) the angle between the normal at entry and the normal at exit
3) the wavelength of light. Short, energetic waves (UV) bend more than long, less energetic wavelengths.

So - refraction in the theatre is the use of lenses.



the ray that enters the glass is bent from its original path toward the normal; the ray that enters air is bent away from the normal. But since the normals are not parallel, the paths in air are not parallel.

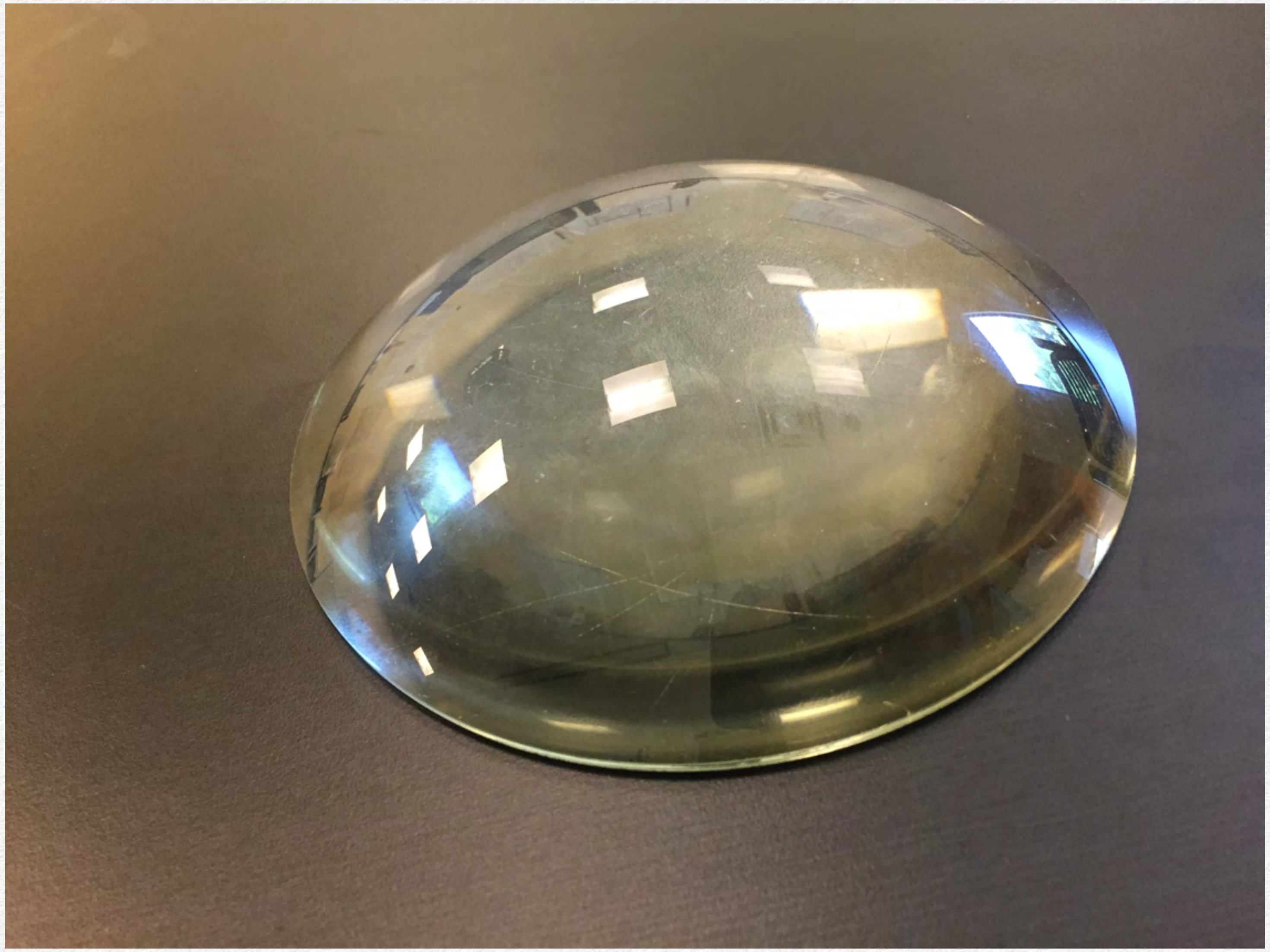
As the angle between the normal at entry and the normal at exit differ, an opportunity arises to control or focus light by creating lenses. Lenses can bend light to concentrate it at an area that is a concentrated point or a focal point.

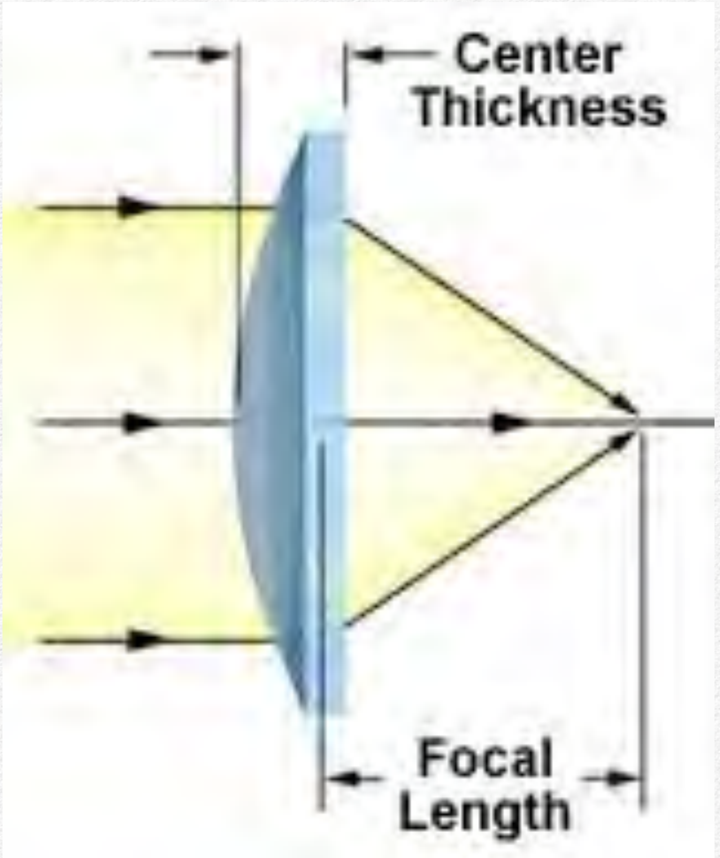
Ellipsoidal lighting instruments, are often designated by the focussing ability of their lenses., for example a “6X12” has a 6” diameter lens with a 12” focal length or a 19 degree focusses light so it exits the instrument at a 19 degree diameter beam of light. With this knowledge, it is easy to calculate the size of a beam of light on stage from a given hanging position.

Lenses used in theatrical lighting instruments are of lesser quality than laboratory lenses due to the cost of lenses. While they bend light just like lab lenses, theatrical lenses are typically made from glass with a higher optical density so they obsorb more light, and they are typically cast instead of ground, so the precision of focussing is less.

The principle type of lens used in theatre applications is called a "**PLANO-CONVEX**" lens which describes the two sides of the lens

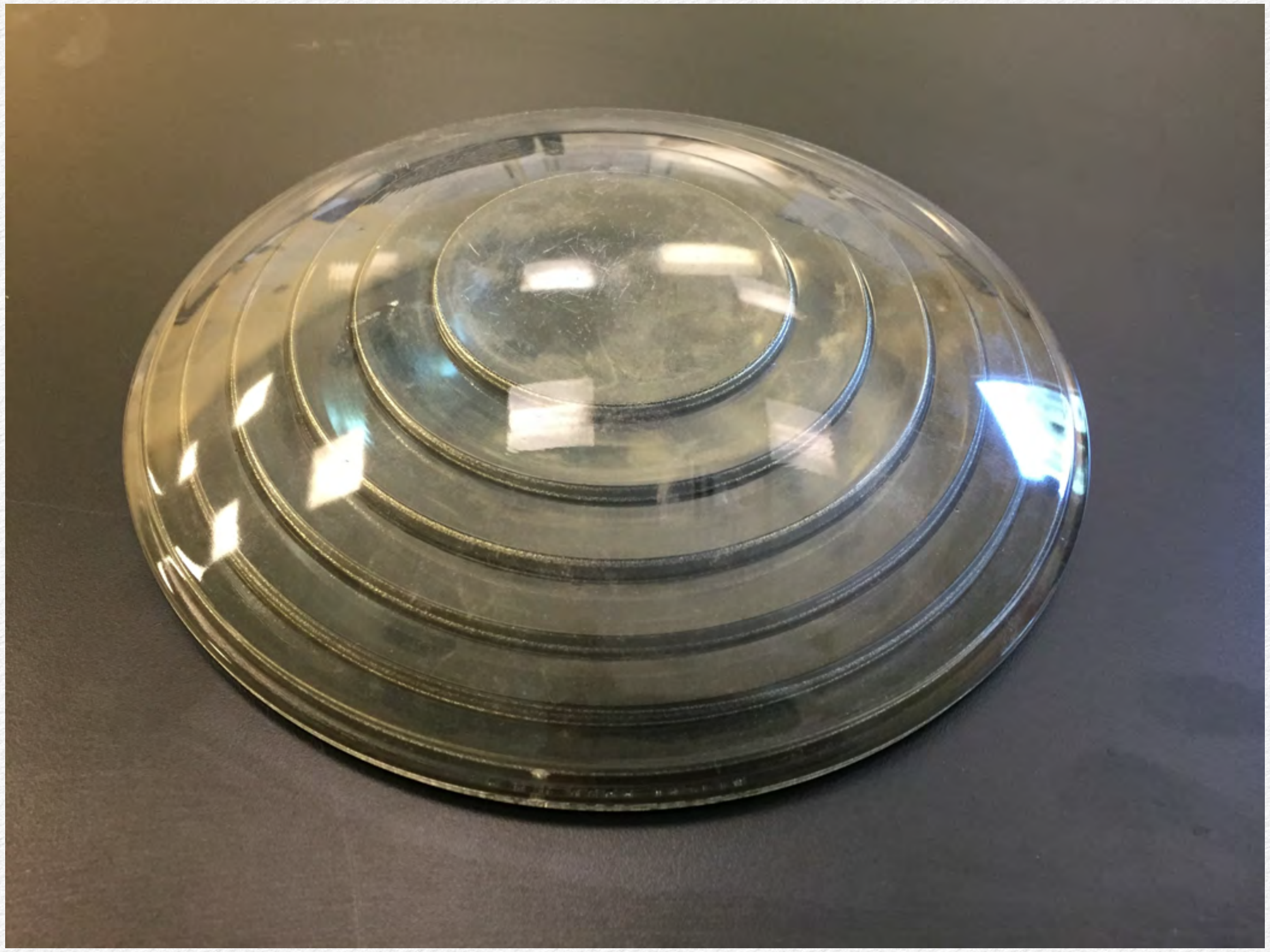
Plano-convex lenses used in theatrical lighting instruments were typically cast (to save costs) and made from glass that is less than optically optimal. Heat build up is a problem with higher temperature tungsten-halogen lamps. This heat build up causes a heat differential on either side of the lens leading to cracking. **Chromatic aberration** is also a fairly major problem. Light from these instruments with a hard focus has a noticable rainbow around the edges. A common scheme to get more bending of light would be to gang two of these lenses together, curved faces towards each other in a configuration called a lens train.





A **STEP LENS** takes this functionality and by stepping the plano side away, allows the lens to have less mass (less glass and less weight) and greater bending power.

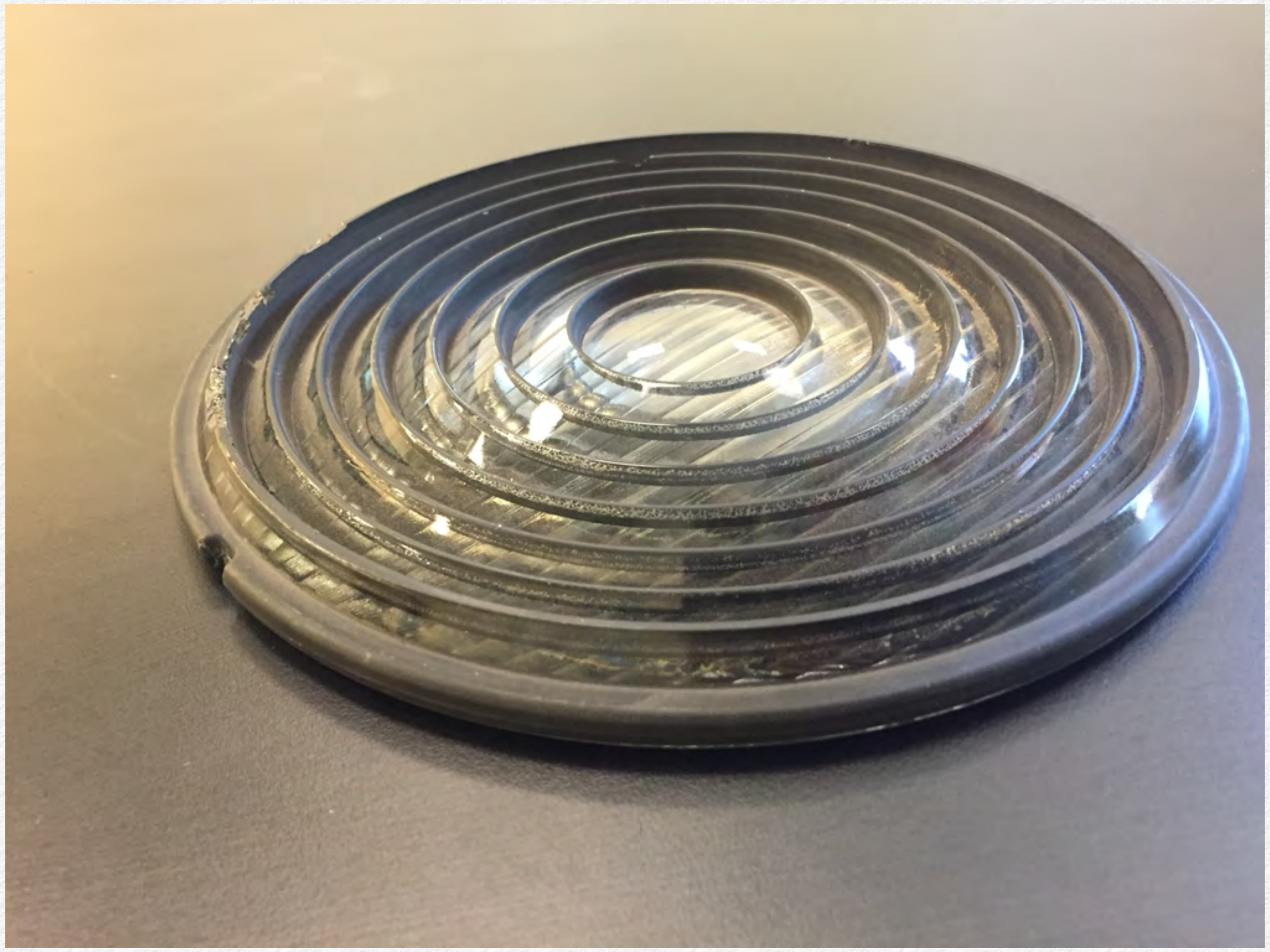
These lenses were lighter than a comparable lens, but were difficult to focus and often created a bulls-eye shape of light /dark areas bordered by rainbows. Each Step in a step lens has the same focal length. These lenses were often found in ellipsoidal instruments designed for long throws, so that added ability to bend light more for tighter focussed beams was very useful.

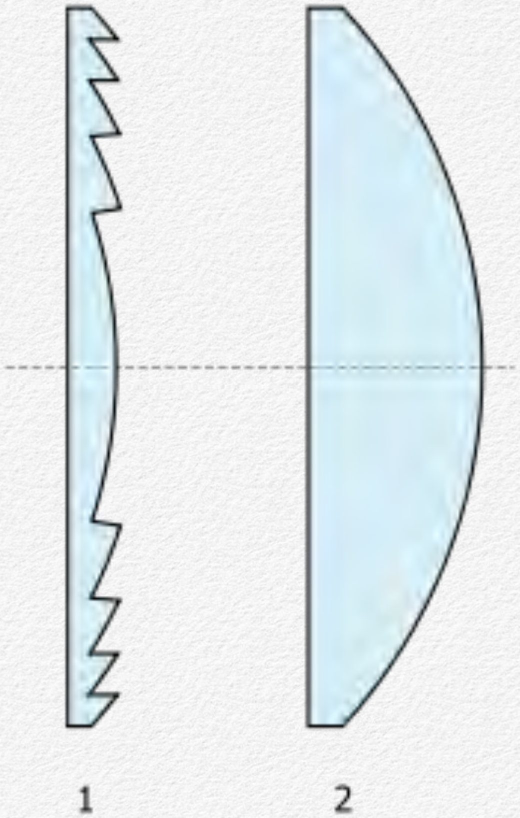


A **FRESNEL LENS**

Invented in 1818 by Augustin-Jean Fresnel for use in light houses.

Uses scheme of cutting away curved side to reduce mass. Each step in a Fresnel lens has a different focal length, providing a softer edge. and, like the step lens,the inital goal was to make a lighter lens, capable of bending and transmitting light more.

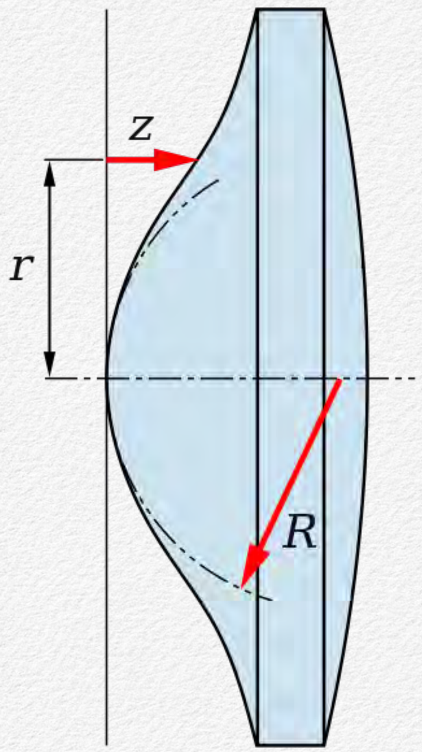


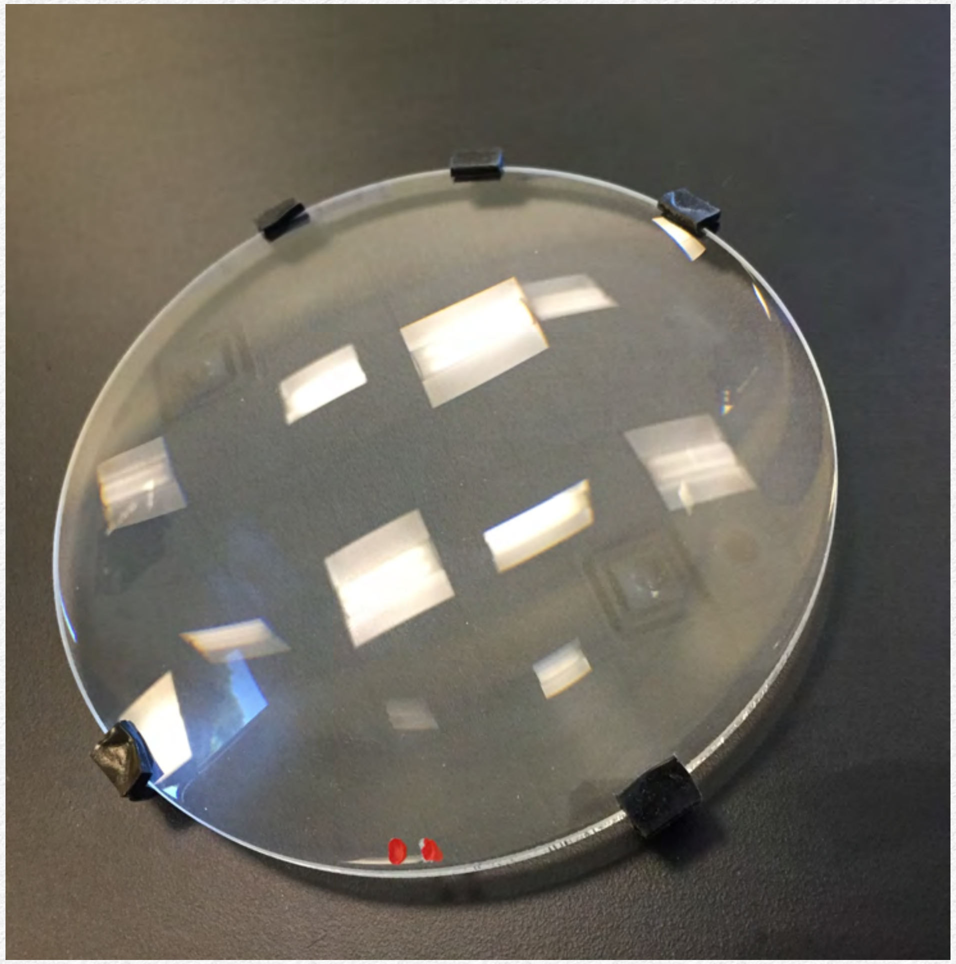


Comparison of a Fresnel lens (left) and a "conventional" plano-convex lens (right). As can be seen, the Fresnel lens simulates the shape of the conventional lens using individual "facets" (also referred to "ridges" or "grooves") - each of which contain a portion of the lens's overall figure. The grooves of the lenses described on this page face "outwards", away from the focal plane. Again, a bulls-eye focusing problem. This was overcome by adding grooves or pebbling to the plano side to diffuse or soften the light.

Fresnel lenses may be made incredibly thin, some are “printed” on plastic to act as lightweight, powerful magnifiers.

Newer lenses, while still cast, are **aspheric** in shape - not a portion of a sphere or cylinder. This an improvement in how the light is focused. It is not unlike using a lens created for the specific "prescription" of the lighting instrument. This results in better focussed light and a flatter field of focus. The glass, a boro-silicate is also of a lower optical density so more light is delivered and less is absorbed by the glass as heat. The lens pictured here is from a 19 degree, ETC source 4 ellipsoidal.





Any lighting instrument using a lens in the theatre is termed a **SPOT LIGHT**, however, not all lighting instruments that create a concentrated beam of light are spotlights. A lens being the requirement for this designation...

Traditional spot lights in the theatre: Ellipsoidals, Fresnels, and PARs

Fresnel - uses a Fresnel lens

ERF or LEKO - used at one time a step lens - today they use a lens “train” of Plano-convex lenses or aspheric lenses.

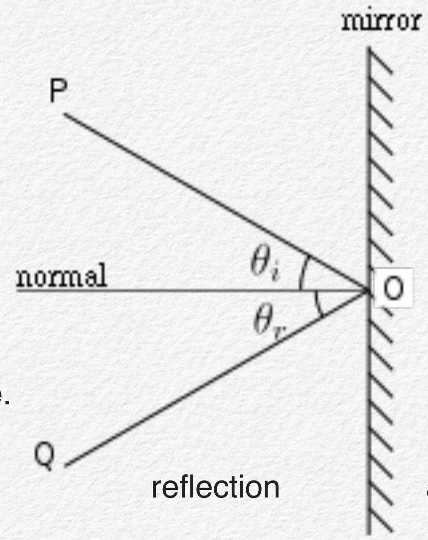
Instruments that don’t use lenses are generally termed “**soft lights**”.

Notice path of light through lens. Use pc lenses to demonstrate the reversing quality of lenses. Note how light can be focused. Where would the light source be?

REFLECTION

THE LAW OF SPECULAR REFLECTION

The angle of incidence = the angle of reflection. Just like playing pool....



When light hits a surface, there are three possible outcomes. Light may be absorbed by the material, light may be transmitted through to the other side, or light may be reflected back. Materials often show some mix of these behaviors, with the proportion of light that goes to each depending on the properties of the material, the wavelength of the light, and the angle of incidence.

the NORMAL is like in refraction, an imaginary line perpendicular to the surface at the point of incidence.

As the surface is curved, light can be concentrated in **FOCAL POINTS** - this is a term for both reflection and refraction.

Reflection types:

Specular (from speculum) = mirror like - image transmission

Mixed = like a varnished floor -

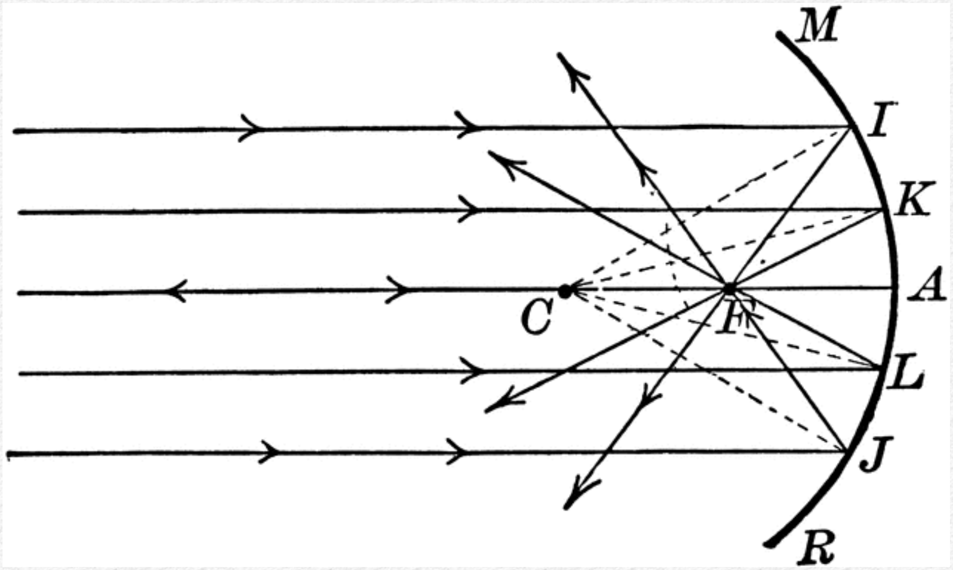
Spread = more diffused - stronger on axis

Diffuse = like white blotter paper

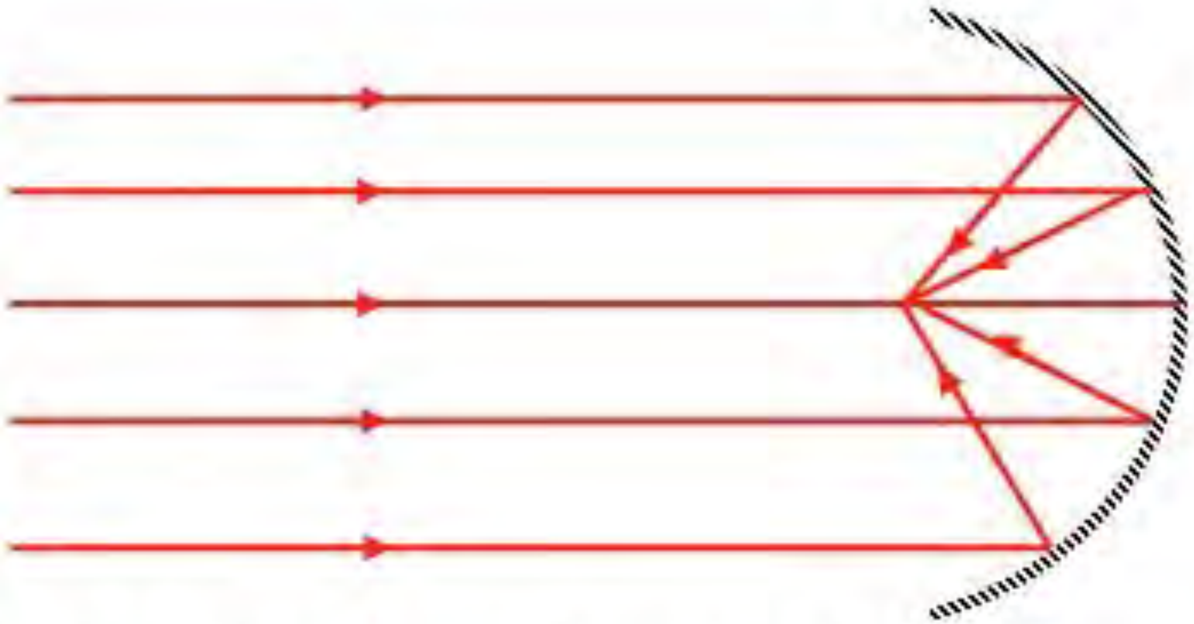
In theatre lighting instruments:

Diffuse reflectors in Olivettes, Scoops and other soft lights

Specular reflectors in Fresnels (spherical)

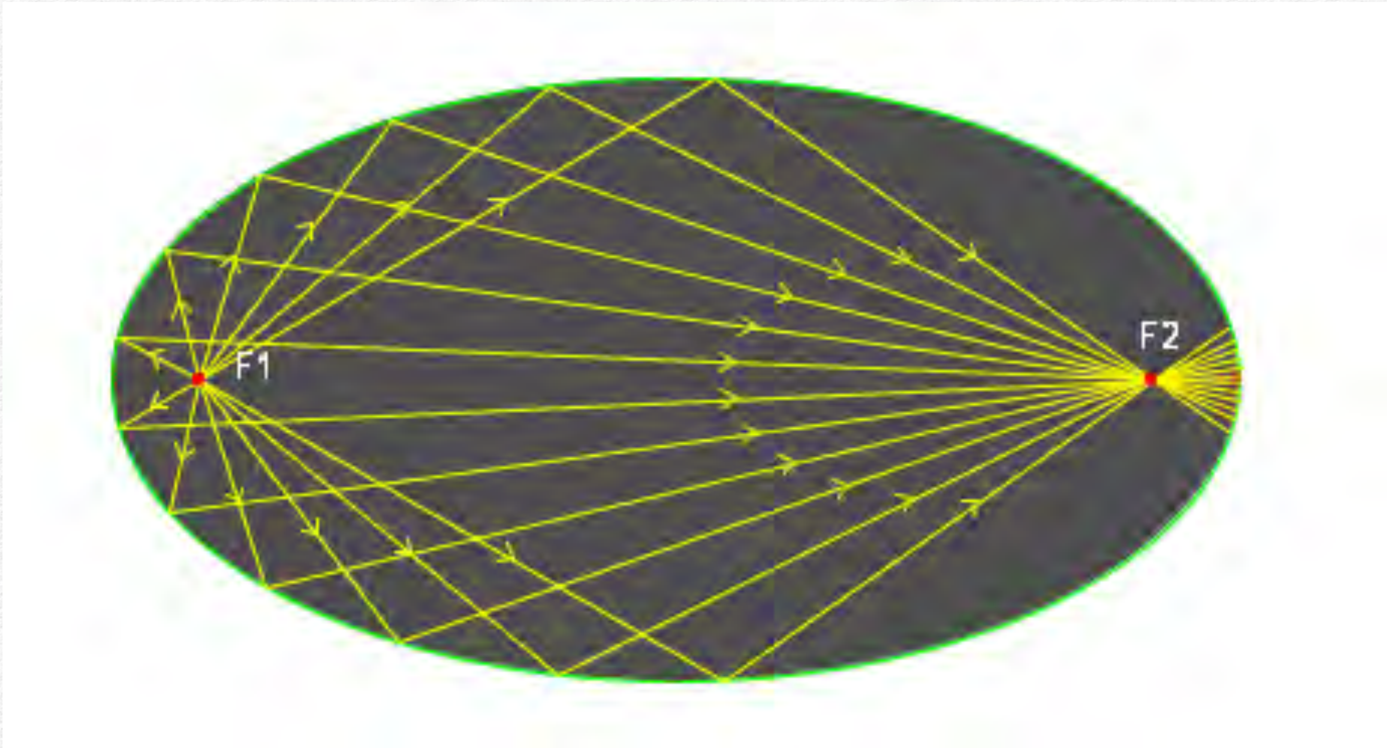


Beam Projectors (Parabolic)



Parabolic mirror focuses all rays onto the principal focus, without spherical aberration.

Ellipsoidals (elliptical) The Ellipsoidal reflector was invented to increase efficiency. has 2 foci. Newer reflectors use flatted segments to get a smoother field.



Which type of reflector might be most efficient at concentrating sunlight?

Needs for a reflector to perform well:

1). reflector, lens and filament must all be on the same optical axis

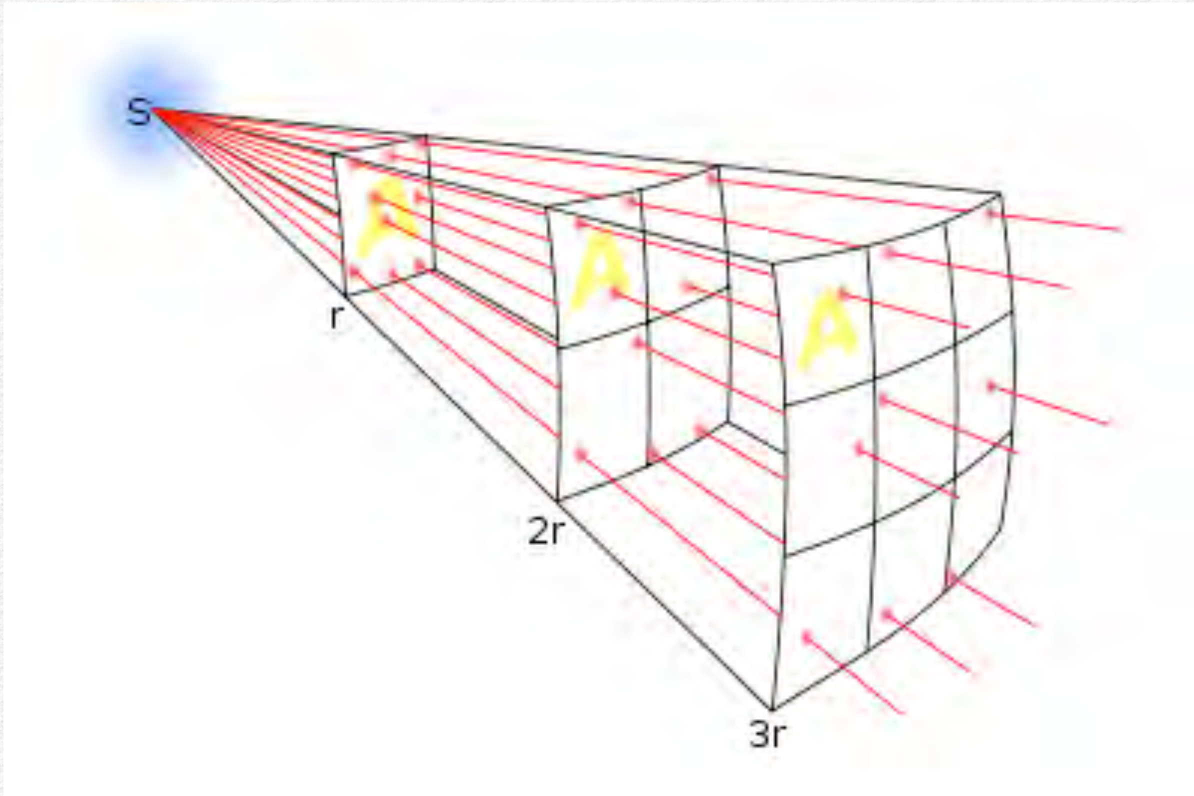
(if they aren't a secondary pool of light will be formed and the instrument will lose efficiency)

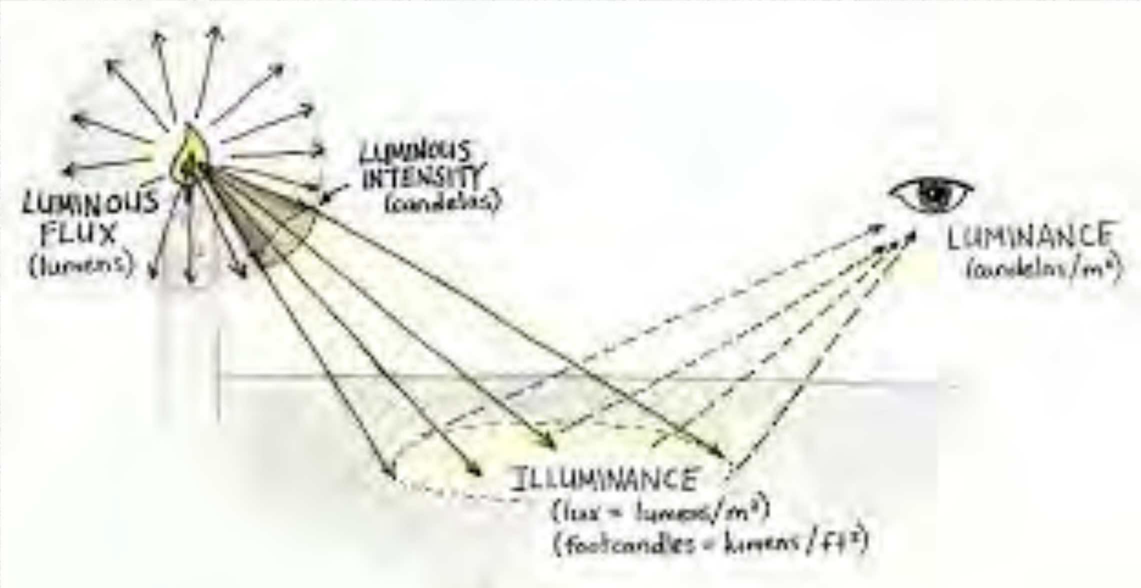
2) The distance from the reflector to the filament must be equal to the radius of the curvature of the reflector, or the reflector will produce a pool of light larger and lose efficiency...

3)The reflector must have a useful diameter sufficient to encompass the largest cone of light to be used by the spotlight - able to handle both spot and flood...

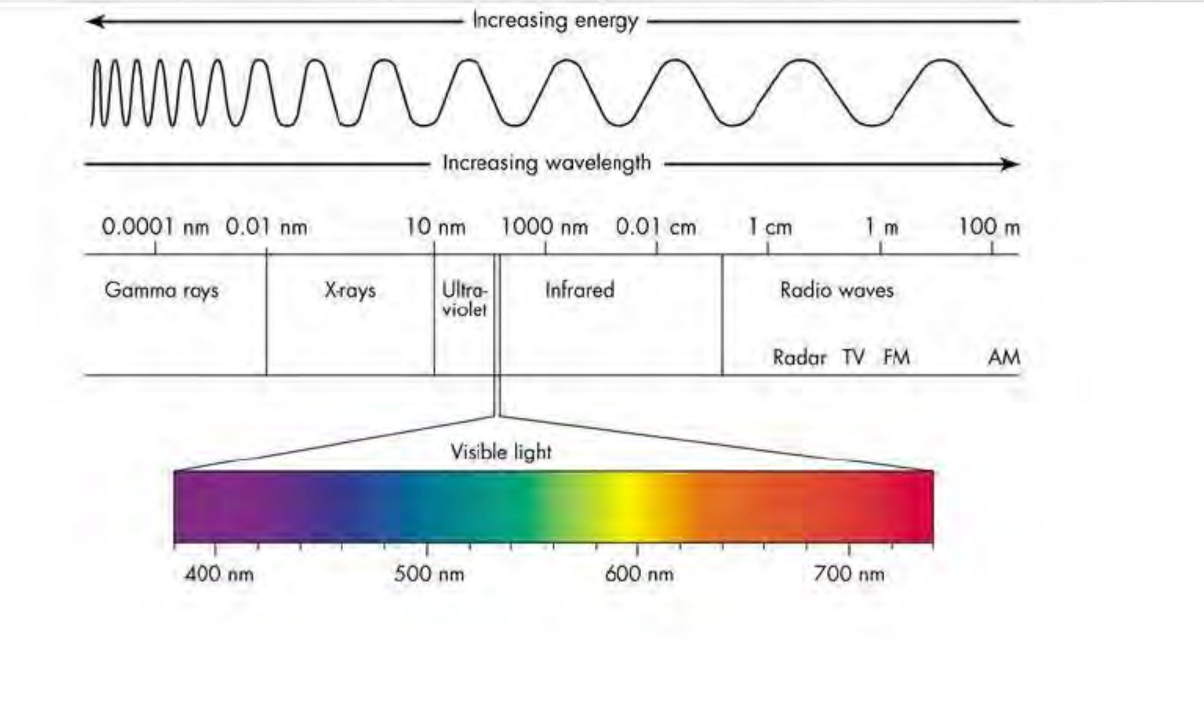
Measuring Light

INVERSE SQUARE LAW :The amount of light is inversely proportional to the square of the distance from the source. In photography and theatrical lighting, the inverse-square law is used to determine the "fall off" or the difference in illumination on a subject as it moves closer to or further from the light source. For quick approximations, it is enough to remember that doubling the distance reduces illumination to one quarter.





Light radiates- as in the rest of the radiant spectrum. Think - the whole electro-magnetic spectrum.



Light travels in measure-able units called wavelengths.

-light is not just a wave but also acts as a particle-hence the uncertainty of quantum physics.

The Human Body can detect infa-red radiation-which we can't see...

(this is the sensation of heat Infa-red radiation = any wavelength longer than .0000276 inch or 800nm

- the body can also detect and react to Ultra-violet light beyond where it is visible. -this reaction is manifested by burns, and cellular breakdown. Ultra-violet is shorter/ higher energy wavelengths. smaller than 370nm.

a spectrum is a display of a series of radiations lined up according to wavelength.

The human eye detects and converts to vision aprox. 800nm-370nm

The Standard Candle = a pre determined point of reference for standardization. Is really a unit of brightness or luminous intensity.(the amount of energy is depended on wavelength)

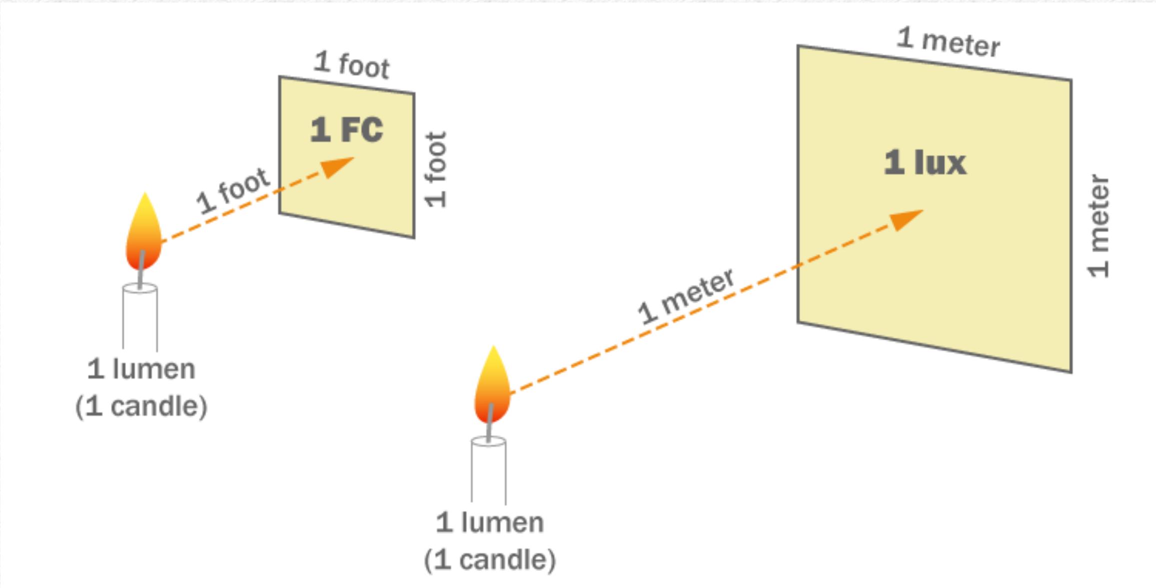
Prior to 1948, was equal to the amount of light from a wax candle made from standardized specifications.

Now

called

the Candela is now = to monochromatic radiation @ 540 X10>12 cycles and has radiant intensity of 1/683 watt per steradian. abreviation :Cd

Foot Candle = the brightness produced on a white surface, 1 foot away from a Standard Candle. expressed as 1fc=1lm/ft2



Foot candles and Lux

“Foot candles” and “lux” are units that indicate the density of light that falls on a surface. This is what light meters measure. For example, average indoor lighting ranges from 100 to 1,000 lux, and average outdoor sunlight is about 50,000 lux.

The footcandle is an older unit based on English measurements. It is equal to one lumen per square foot.

It is being replaced by lux, a metric unit equal to one lumen per square meter. One foot candle is 10.76 lux.

Although foot candles are now officially obsolete, they probably will continue to be used because many existing light meters are calibrated in foot candles.

The general term for lux or foot candles is “illuminance.” The general term is sometimes used by lighting engineers, but the units of lux or foot candles are more commonly used. You use foot candles or lux to measure the adequacy of lighting on the task. Foot candles and lux relate only to the task area, not to the lighting equipment or to the geometry of the space. For example, you could create an illumination level of 100 lux on a surface by using a single spotlight located far away, or by using many cove lights nearby.

Candlepower

“Candlepower” is a measure of lighting concentration in a light beam. It is used primarily with lamps that focus, such as spotlights and PAR lamps. In lamps where candlepower is specified, the candlepower rating usually applies only to a small spot in the


A lumen is the true measurement of light output and brightness.

Incandescent	Lumens	LED Most efficient	CFL More efficient	Halogen/Incandescent Efficient
100W	1600	up to 23W	up to 26W	up to 72W
75W	1100	up to 17W	up to 20W	up to 53W
60W	800	up to 12W	up to 15W	up to 43W
40W	450	up to 8W	up to 11W	up to 29W

center of the beam.

Relationship between illuminance and irradiance[from wikipedia)

Like all photometric units, the lux has a corresponding "radiometric" unit. The difference between any photometric unit and its corresponding radiometric unit is that radiometric units are based on physical power, with all wavelengths being weighted equally, while photometric units take into account the fact that the human eye's image-forming visual system is more sensitive to some wavelengths than others, and accordingly every wavelength is given a different weight. The weighting factor is known as the luminosity function.

The lux is one lumen per square metre (lm/m2), and the corresponding radiometric unit, which measures irradiance, is the watt per square metre (W/m2). There is no single conversion factor between lx and W/m2; there is a different conversion factor for every wavelength, and it is not possible to make a conversion unless one knows the spectral composition of the light.

The peak of the luminosity function is at 555 nm (green); the eye's image-forming visual system is more sensitive to light of this wavelength than any other. For monochromatic light of this wavelength, the amount of illuminance for a given amount of irradiance is maximum: 683.002 lux per W/m2; the irradiance needed to make one lux at this wavelength is about 1.464 mW/m2. Other wavelengths of visible light produce fewer lux per watt-per-meter-squared. The luminosity function falls to zero for wavelengths outside the visible spectrum.

For a light source with mixed wavelengths, the number of lumens per watt can be calculated by means of the luminosity function. In order to appear reasonably "white," a light source cannot consist solely of the green light to which the eye's image-forming visual photoreceptors are most sensitive, but must include a generous mixture of red and blue wavelengths to which they are much less sensitive.

This means that white (or whitish) light sources produce far fewer lumens per watt than the theoretical maximum of 683.002 lm/W. The ratio between the actual number of lumens per watt and the theoretical maximum is expressed as a percentage known as the luminous efficiency. For example, a typical incandescent light bulb has a luminous efficiency of only about 2%.

In reality, individual eyes vary slightly in their luminosity functions. However, photometric units are precisely defined and precisely measurable. They are based on an agreed-upon standard luminosity function which is based on measurements of the spectral characteristics of image-forming visual photoreception in many individual human eyes.

LUMEN = the quantity of light it takes to illuminate one square foot to the brightness of one foot candle

in terms of electrical energy, 1 lumen =+/-0.001496 watt

Lumen output is in all directions-it is up to the consumer to get it to go where it is needed.

“Lumen” is the unit of total light output from a light source. If a lamp or fixture were surrounded by a transparent bubble, the total rate of light flow through

the bubble is measured in lumens. Lumens indicate a rate of energy flow. Thus, it is a power unit, like the watt or horsepower.

Typical indoor lamps have light outputs ranging from 50 to 10,000 lumens. You use lumens to order most types of lamps, to compare lamp outputs, and to calculate lamp energy efficiencies (which are expressed as lumens per watt).

Note that lumen output is not related to the light distribution pattern of the lamp. A large fraction of a lamp’s lumen output may be useless if it goes in the wrong directions.

Flux or luminous flux = the total amount of light generated by a source, per unit of time, expressed in lumens- does not describe distribution or direction

Comfortable reading light- to the point your Mother won’t tell you that you are going to put out your eyes - is about 30 foot candles.