Ch.15 Lamps, luminaires, and controls

General remarks

- This chapter deals with electric light sources
- Daylight sources (Ch.10):
  - Direct: sunlight, diffuse skylight
  - Indirect: reflected or modified from its primary source
- Electric light sources (Ch.15)
  - Incandescent lamps: incandescent, tungsten-halogen types
  - Discharge lamps: fluorescent, mercury vapor, metal halide, high pressure and low pressure sodium lamps, induction lamps
  - LED lamps

General remarks

- Edison’s first practical incandescent lamp (1870-1880s)
- The fluorescent lamp (1937) has revolutionized the workplace.
- Understanding the characteristics of light sources is important: illuminance, luminance, view, visual comfort, thermal comfort, energy use, etc.

Efficacy

- The efficiency of a light source: lumen/watt (must include ballast losses)
- Incandescent lamp: 7% light + 93% released as heat out of total electrical energy.
- The most desirable form of lighting: daylight (about 120 lumen/watt)
- Electrical lighting in US nonresidential buildings consumes 25% to 60% of the electric energy.

TABLE 10.1 Efficacy of Various Light Sources

Source	Efficacy (Lm/W)
Candle	0.1
Oil lamp	0.3
Original Edison lamp	1.4
1910 Edison lamp	4.5
Incandescent lamp (15–500 W)	8–22
Tungsten–halogen lamp (50–1500 W)	18–22
Fluorescent lamp (15–215 W)[a]	35–80
Compact fluorescent lamp[b]	55–75
Mercury-vapor lamp (40–1000 W)[a]	32–63
Metal-halide lamp (70–1500 W)[a]	80–125
High-pressure sodium lamp (35–100 W)[a]	55–115
Induction lamp[c]	48–70
Sulfur lamp[c]	90–100
Direct sun (low altitude = 7.5°)	90
Direct sun (high altitude > 25°)	117
Direct sun (mean altitude)	100
Sky (clear)	150
Sky (average)	125
Global (average)	115
Maximum source efficacy predicted (in the year 2010)	150
Maximum theoretical limit of source efficacy	250 (approximate)

[a] Includes ballast losses (with electronic ballasts, lumens per watt become much higher). Losses vary between ballasts and manufacturers.

[b] With electronic ballasts.

[c] With a power supply.

Incandescent filament lamps

직선 → 코일 → 2중코일
전기저항이 아주 높음,
열과 동시에 백열광 발생
(필라멘트가 소산되면서,
램프 수명이 끝남)

전구의 흑화 및
필라멘트 소산 방지

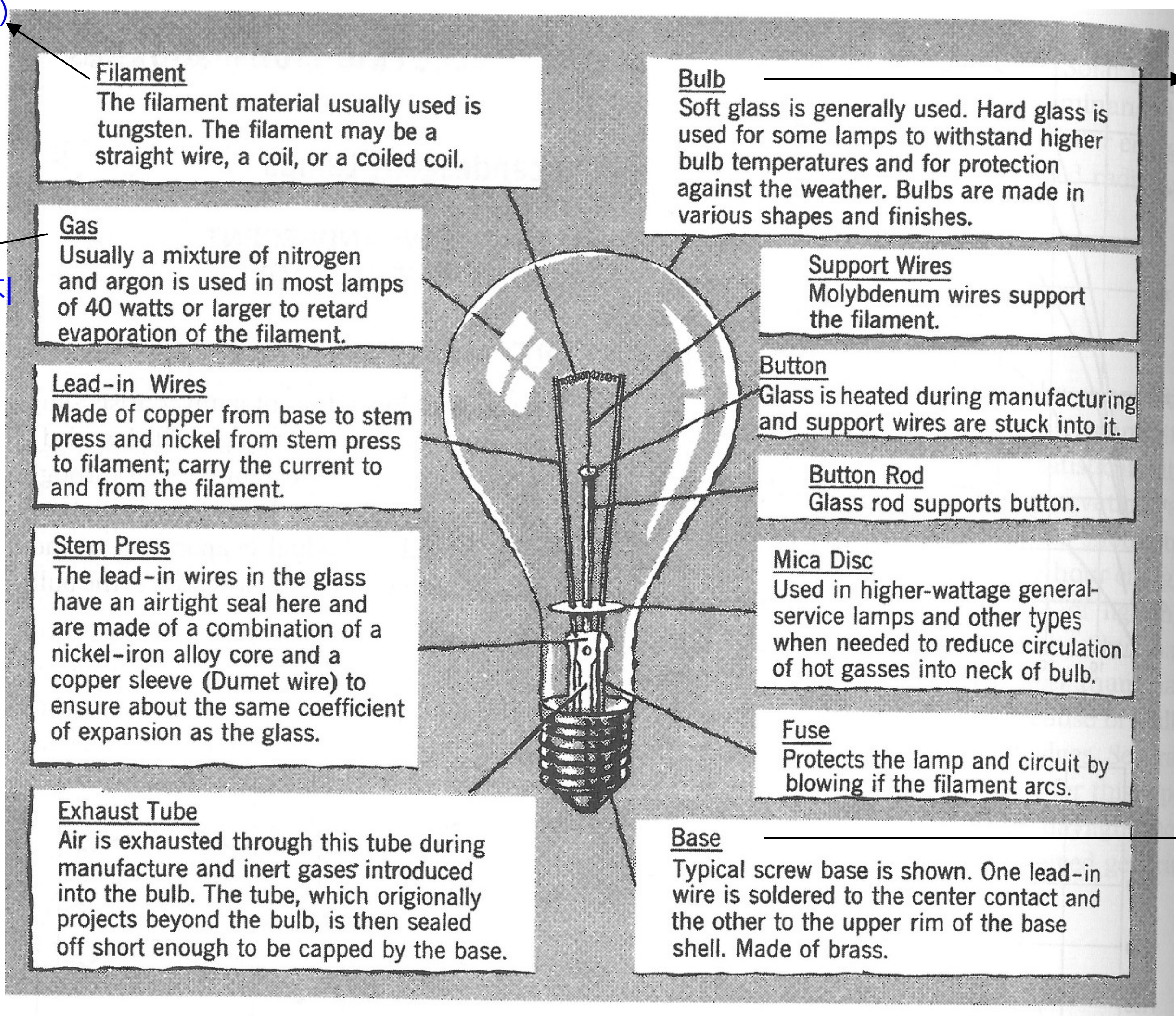


Fig. 12.7 Construction of a standard incandescent lamp.

Coated with silica to diffuse light.
Light output은 2-3% 줄어듬
Color coating도 쓰임

대개는 screw base.
300W 보다 큰 경우, 램프가 반사경이나 렌즈에 특수하게 부착되는 경우에는 특수 base 사용 (Fig.15.1)

This figure from 10th Ed.

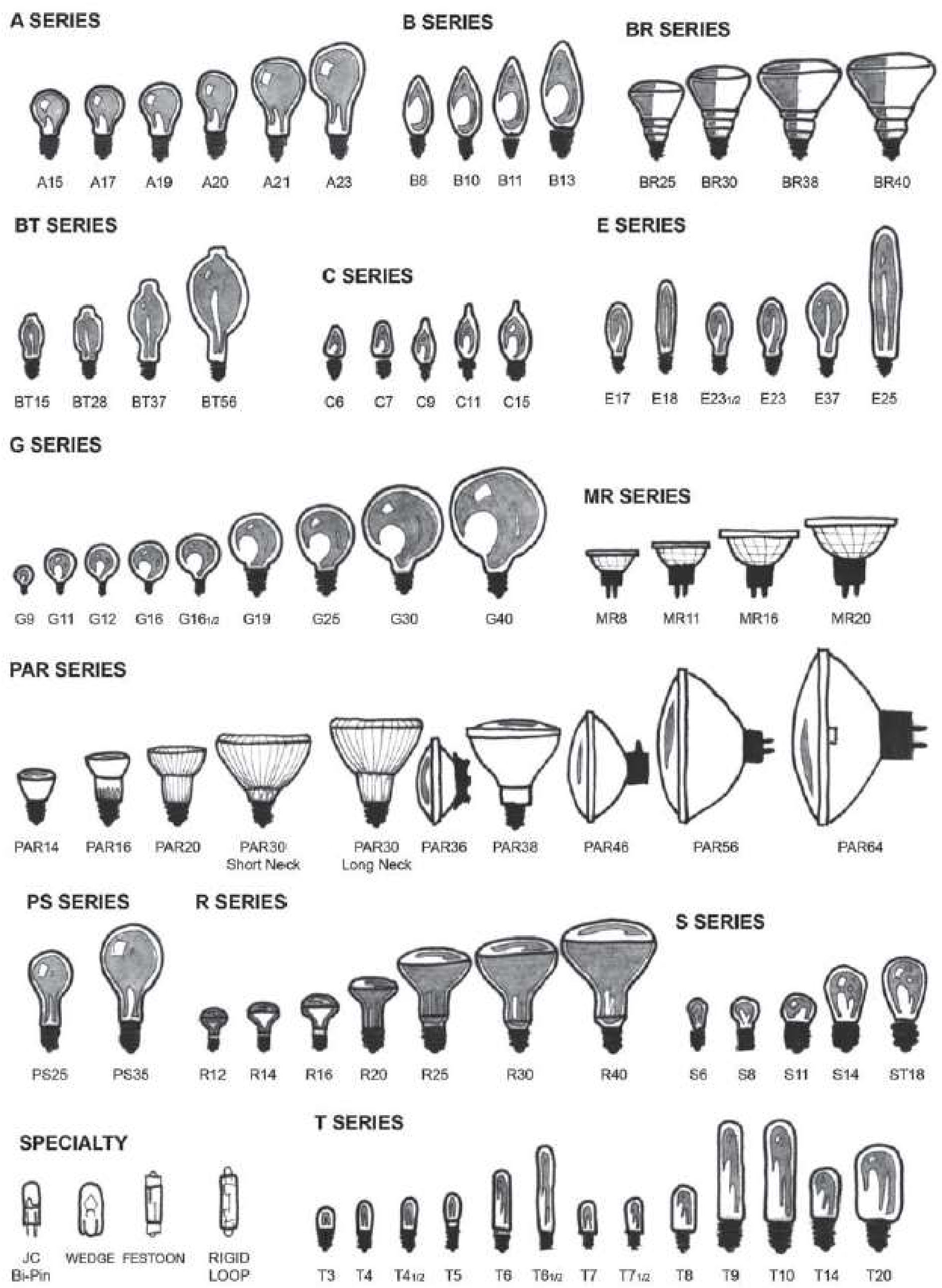
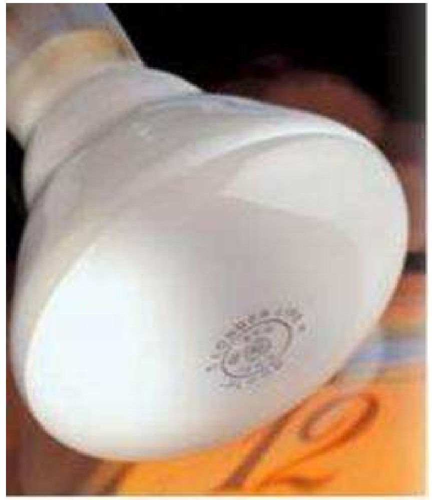


Fig. 15.1 *(a) Common incandescent lamp bulb and (b) base types with associated nomenclature. Bulb nomenclature indicates type and size. The letter is an abbreviation of the shape, and the number is the diameter in eighths of an inch. An A-19 is a standard shaped bulb $^{19}/_{8}$ inch in diameter. A PAR-38 is a parabolic reflector lamp $^{38}/_{8}$ inch in diameter. (Drawing by Samantha Ruddy, © University of Oregon, Baker Lighting Lab.)*



Source: GE Lighting

Incandescent reflector lamp: reflective coating

Reflector Lamps are made in "R," "BR," "ER," and "PAR" shapes (see Fig. 15.1). R: Reflector

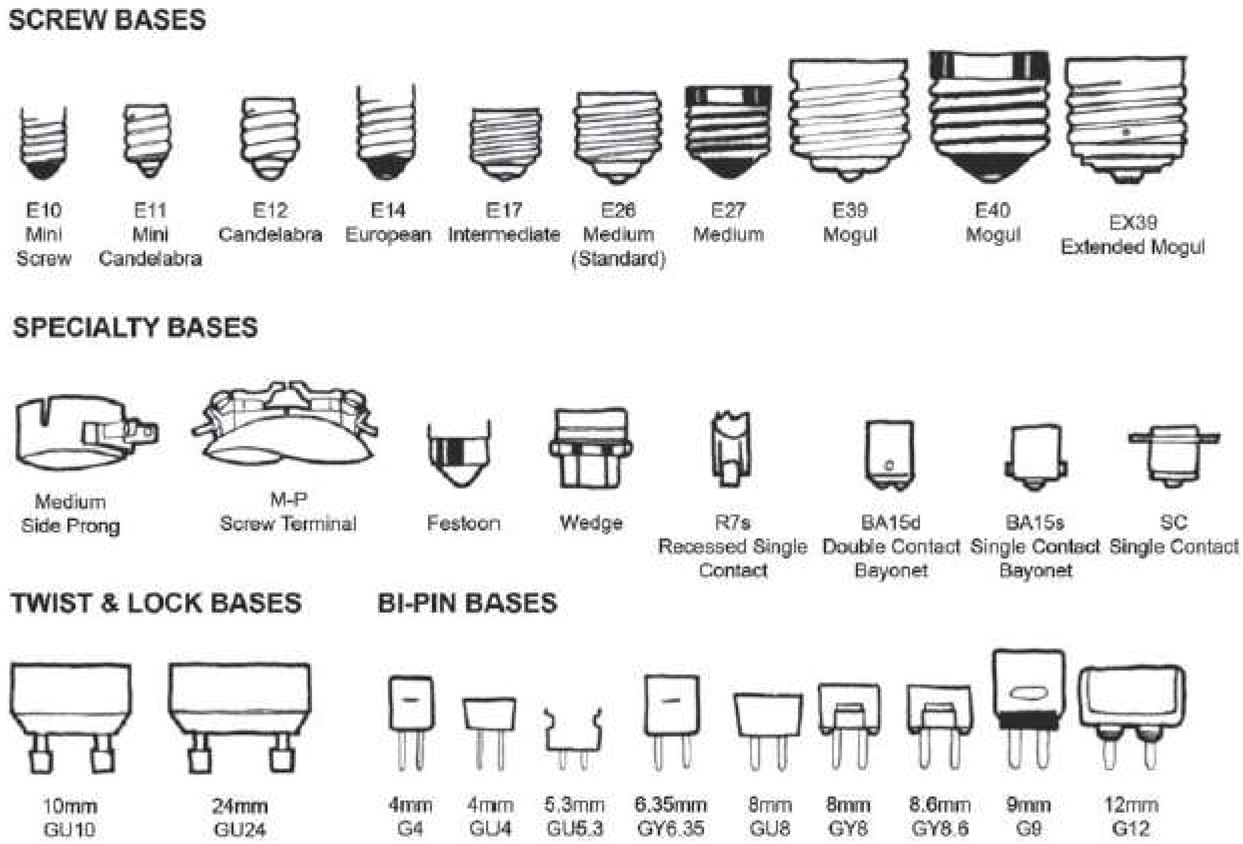
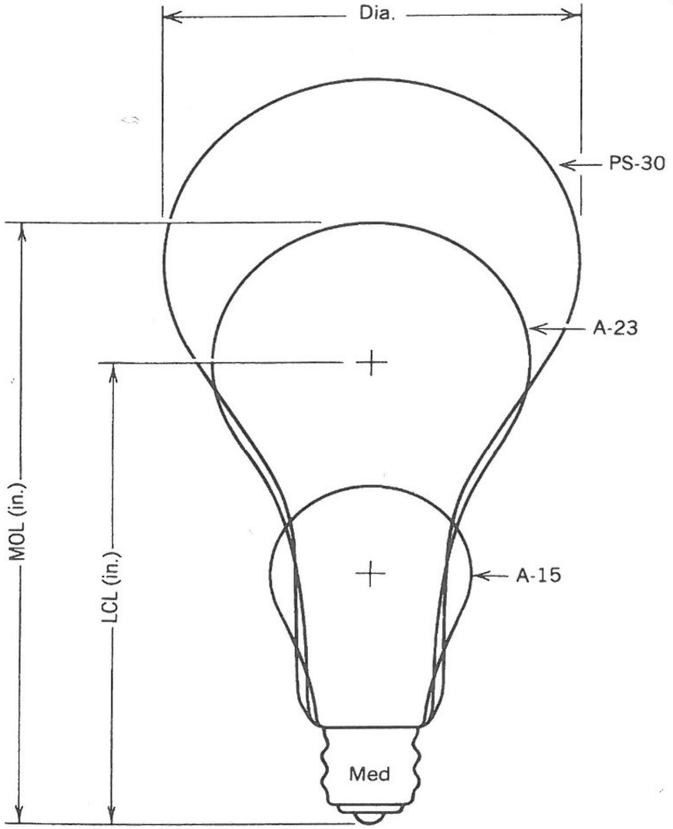


Fig. 15.1 *(continued)*



Bulb diameter is given in $\frac{1}{8}$ in. (0.3 cm) Example: An A-19 bulb has a diameter of $\frac{19}{8}$ in. or $2\frac{3}{8}$ in. (6 cm)

MOL:Maximum overall length: This figure refers to the maximum length of the bulb.

LCL:Light center length: This dimension, important when designing reflectors, is measured from the filament to a point that varies with base type.

	A – STANDARD SHAPE									PS – PEAR SHAPE							
WATTS	15	25	40	60	75	100	100	150	150	150	200	300	300	500	750	1000	1500
BULB	A–15	A–19$_1$	A–19$_2$	A–19$_3$	A–19$_3$	A–19$_3$	A–21$_1$	A–21$_2$	A–23	PS–25	PS–30	PS–30	PS–35	PS–40	PS–52	PS–52	PS–52
DIAMETER"	$1\frac{7}{8}$	$2\frac{3}{8}$	$2\frac{3}{8}$	$2\frac{3}{8}$	$2\frac{3}{8}$	$2\frac{3}{8}$	$2\frac{5}{8}$	$2\frac{5}{8}$	$2\frac{7}{8}$	$3\frac{1}{8}$	$3\frac{3}{4}$	$3\frac{3}{4}$	$4\frac{3}{8}$	5	$6\frac{1}{2}$	$6\frac{1}{2}$	$6\frac{1}{2}$
M.O.L."	$3\frac{1}{2}$	$3\frac{7}{8}$	$4\frac{1}{4}$	$4\frac{7}{16}$	$4\frac{7}{16}$	$4\frac{7}{16}$	$5\frac{1}{4}$	$5\frac{1}{2}$	$6\frac{3}{16}$	$6\frac{15}{16}$	$8\frac{1}{16}$	$8\frac{1}{16}$	$9\frac{3}{8}$	$9\frac{3}{4}$	13	13	13
L.C.L."	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{15}{16}$	$3\frac{1}{8}$	$3\frac{1}{8}$	$3\frac{1}{8}$	$3\frac{7}{8}$	4	$4\frac{5}{8}$	$5\frac{3}{16}$	6	6	7	7	$9\frac{1}{2}$	$9\frac{1}{2}$	$9\frac{1}{2}$
BASE	MED	MED	MED	MED	MED	MED	MED	MED	MED	MED	MED	MED	MOG	MOG	MOG	MOG	MOG
STANDARD FINISH	IF	IF	IF W	IF	IF	IF	IF	IF	CL IF	CL IF	IF	IF	IF	IF	CL IF	CL IF	CL IF

CL – CLEAR IF – INSIDE FROSTED → 우유 빛 코팅

1/8인치 단위 (← BULB)

Base type에 따라 측정 기준점 다름, Fig.15.1 하단 참조 (← L.C.L.)

This figure from 10th Ed.

Fig. J.1 *Typical dimensional data for common general-service incandescent lamps.*

Operating characteristics

- 전압이 변화하면 필라멘트 온도가 변화하고, lumen/watt, watt, 수명도 변화

120V 램프를 125V (104.2%)에서 사용할 경우

- 16% more light (lumens): 광속 증가
- 7% more power consumption (watts): 전력소비 증가
- 8% higher efficacy: 효율 증가
- 42% less lamp life: 수명감소

120V 램프를 115V (95.8%)에서 사용하면,

- 15% less light
- 7% less power consumption
- 8% lower efficacy
- 72% more lamp life

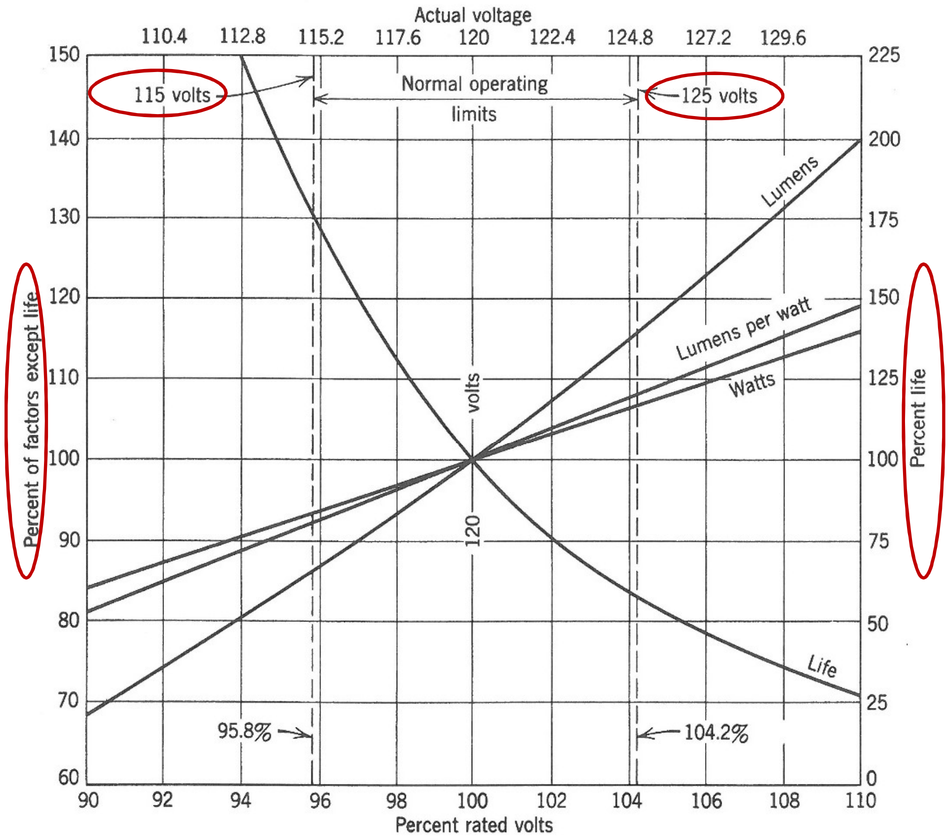


Fig. J.2 Characteristics of a standard 120-V general-service incandescent lamp as a function of voltage.

This figure from 10th Ed.

TABLE 15.1 Comparison of Operating Characteristics

Operation of Lamps	120-V lamp at 125 V (104.2%)	120-V lamp at 115 V (95.8%)
Amount of light (lumens)	16% more	15% less
Power consumption (watts)	7% more	7% less
Efficacy (lumens per watt)	8% higher	8% lower
Life (hours)	42% less	72% more

Undervoltage vs. overvoltage

- (favor of overvoltage) where lamps are replaced before burnout on a group replacement system and initial installation cost per lux and/or energy costs are high
  - Lamps may be operated overvoltage, thereby increasing light output and efficiency, but shortening life.
    - Ex.: sports-lighting installations:
      - Because of the high installation cost of tower-mounted flood lights, it is mandatory to extract the maximum light from each unit.
      - In stadium installations (yearly lamp operation <= 200h), 10% overvoltage operation doubles the light output but still allows a once-a-year off-season relamping → a highly economical procedure. (Refer to Fig. J.2)
- (favor of undervoltage) where lamp displacement is difficult and/or expensive
  - Lamps may be operated slightly undervoltage and life prolonged, thereby deceasing the frequency of replacement
  - As a result, the lamp efficiency is decreased
- In general, operate the lamps at rated voltage.

Other characteristics

- Lumen maintenance: Light output decreases slowly with lamp life as the bulb blackens. (Fig. 15.3)
- Color: yellow-red dominated
- Surroundings: impervious to external heat, cold or humidity.
- Lamp efficacy: Incandescent lamps produce light as a by-product of heat; inherently inefficient.
  - Efficacy increases with wattage. (Table J.1): one 100-W lamp produces light as much as two 60-W lamps.
- Lamp life: very short (Table J.1)

From 10th Ed.

TABLE J.1 Typical Incandescent Lamp Data (Listing a Few of the Many Sizes and Types of 115-, 120-, and 125-V Lamps)

Extended long life lamp

Regular lamp

Lamp Watts[a]	Average Rated Life (h)	Approximate Color Temperature[b] (K)	Initial Lumens	Lumens per Watt[c]	Shape of Bulb[d]	Base	Description
15	2,500	—	126	8.4	A-15	Med	Long life
25	1,000	—	240	9.6	A-19	Med	Rough service
25	2,500	2,500	232	9.3	A-19	Med	—
40	1,500	—	495	12.4	A-19	Med	—
50	2,000	—	525	10.5	ER30	Med	—
60	1,000	2,800	890	14.8	A-19	Med	—
60	2,500	—	800	13.3	A-19	Med	Long life
75	750	—	1,220	16.3	A-19	Med	—
100	750	2,870	1,650	16.5	A-19	Med	—
100	750	—	1,750	17.5	A-21	Med	—
100	2,500	—	1,500	15.0	A-19	Med	Long life
135	750	—	2,425	18.0	A-21	Med	Economy
150	750	2,900	2,810	18.7	A-21	Med	—
150	750	—	2,600	17.3	PS-25	Med	—
200	750	2,930	4,000	20.0	A-23	Med	—
300	750	2,940	6,300	21.0	PS-25	Med	—
500	1,000	3,000	10,850	21.7	PS-25	Mogul	—

[a]Figures in this column designate the input watts thus: 60 = 60 W.
[b]See Section 11.34.
[c]Luminous efficacy, in lumens per watt, increases with filament temperature and, therefore, with wattage.
[d]See Fig. 12.8.

Pros vs. cons

- Advantages of incandescent lamps
  - low initial cost
  - instant start and restart
  - Very simple to dim
  - simple, compact installations (no accessories, no ballasts)
  - cheap fixtures
  - focusability as a point source
  - lamp life independent of the number of starts
  - good color rendition

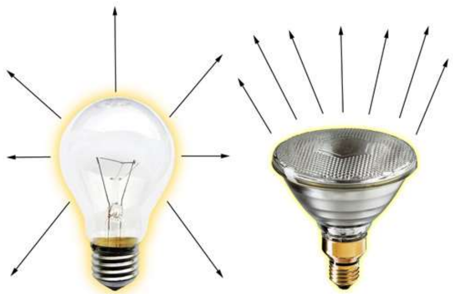
- Disadvantages of incandescent lamps
  - Very low efficacy → more fixtures and large heat gain
  - high lamp heat generation
  - Short lamp life → high lamp replacement labor cost
  - Critical voltage sensitivity
  - Careful fixture design (to avoid glare) due to light concentration of the filament (point source)

Applicable areas

- Because of its poor energy characteristics and short lamp life,
  - Infrequent use
  - Frequent short-duration use
  - Where low-cost dimming is required
  - Where the point source characteristics of the lamp is important, as in focusing fixtures
  - Where minimum initial cost is essential
  - Where its characteristics of color rendering is desired

Special incandescent lamps

- Rough service and vibration lamps: built to withstand rough handling and continuous vibration. Lower efficacy than general incandescent lamps.
- Extended service (long-life) lamps: 2,500h (Table J.1)
  - Useful where relamping is difficult and maintenance is irregular.
  - Long life lamps are designed for higher voltages than that which is applied. So, lower efficacy, more life.
  - 장수명 전구로 비싼 가격에 판매되나, 일반 백열전구와 동일하며, 효율이 상당히 낮아, 사용시에는 유의해야 함(일반적으로 사용이 권장되지 않음)
- Reflector lamps
  - Reflector Lamps are made in "R," "BR," "ER," and "PAR" shapes (see Fig. 15.1).
  - narrow (spot) or wide (flood) beam
- Energy-saving lamps (http://www.energystar.gov/): Energy Star program recommends Energy Star-qualified lighting



Light Output of Type A Incandescent Bulb Light Output of Reflector Type Bulb (PAR)

incandescent reflector lamp

Tungsten-Halogen lamps
(일명 Quartz-Iodine lamp)

- Similar to incandescent lamp. It differs in that a small amount of halogen gas (iodine or bromine) is added to the inert gas mixture that fills a small capsule, constructed of quartz glass, surrounding the filament within the bulb of the lamp.
- This addition results in retardation of filament evaporation, which is the usual cause of incandescent lamp failure, and thereby extends lamp life (2,000-3,000 h)(Fig. 15.3).

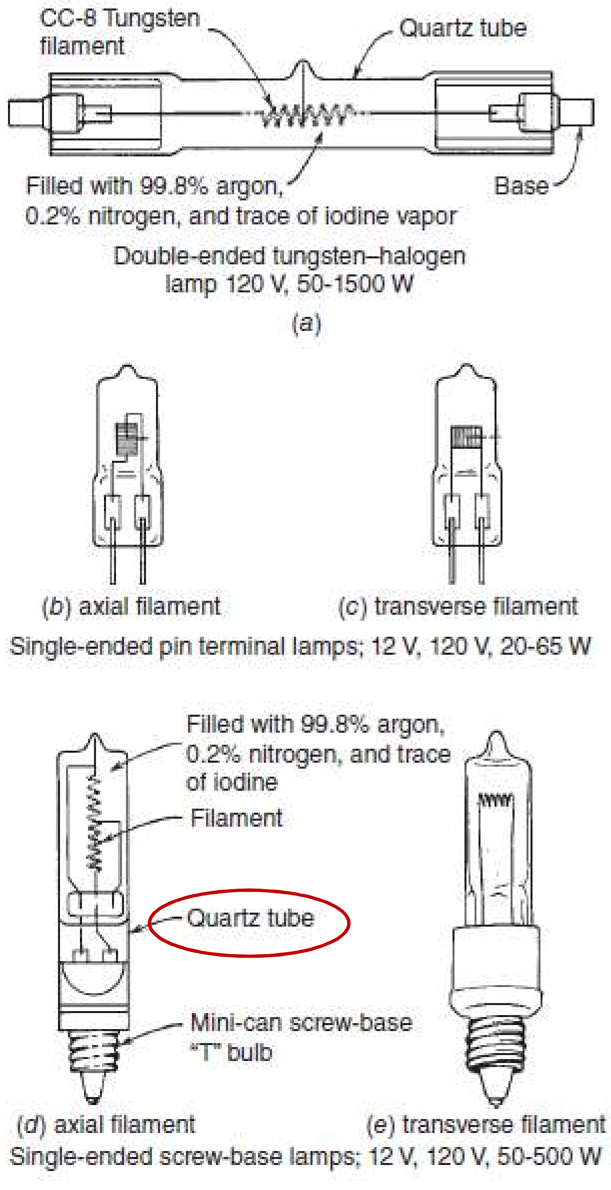


Fig. 15.2 Common tungsten-halogen lamps are available in a variety of designs.

Compared to incandescent lamp

- Similarities
  - It produces light by heating a filament
  - Color temperature (2000-3400K)
  - Simple and inexpensive dimming
- Differences
  - Extended lamp life due to halogen gas
  - Efficacy: slightly higher efficacy
  - Lower lumen depreciation (98% output at 90% life) (Fig. 15.3)
  - A smaller bulb for a given wattage → good for point source
  - The high temperature required for the halogen → a compact and high-temperature filament required → the lamp is effectively a point source → ideal for use in precision reflectors (정밀 반사경, 슬라이드, OHP)
  - Due to the lamp's high filament temperature, the bulb envelope is generally made of quartz or a special high-temperature glass, which can withstand high temperatures better than glass (고온의 전구온도로 인해, 전구의 갑작스런 파열 가능 → shield가 반드시 필요 (lens, screen, etc.)

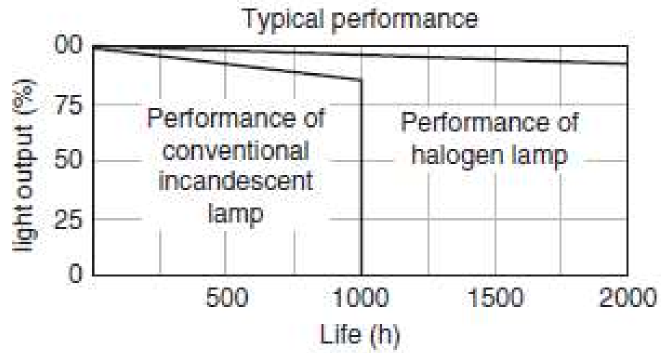


Fig. 15.3 The self-regenerative halogen cycle slows the evaporation of the tungsten filament, and consequently lowers light loss depreciation and lengthens the lamp life compared to a standard incandescent lamp.

Tungsten-Halogen lamp types

- Basic type: Fig. 15.2
- Encapsulated lamps: Figs. 15.4, 15.5
  - Lamps are sealed (encapsulated)
- MR-16 precision reflector units
  - 2 inch diameter multifaceted dichroic (heat-rejecting) reflector
  - Display and accent lighting before the advent of a viable LED alternative

Encapsulated lamps

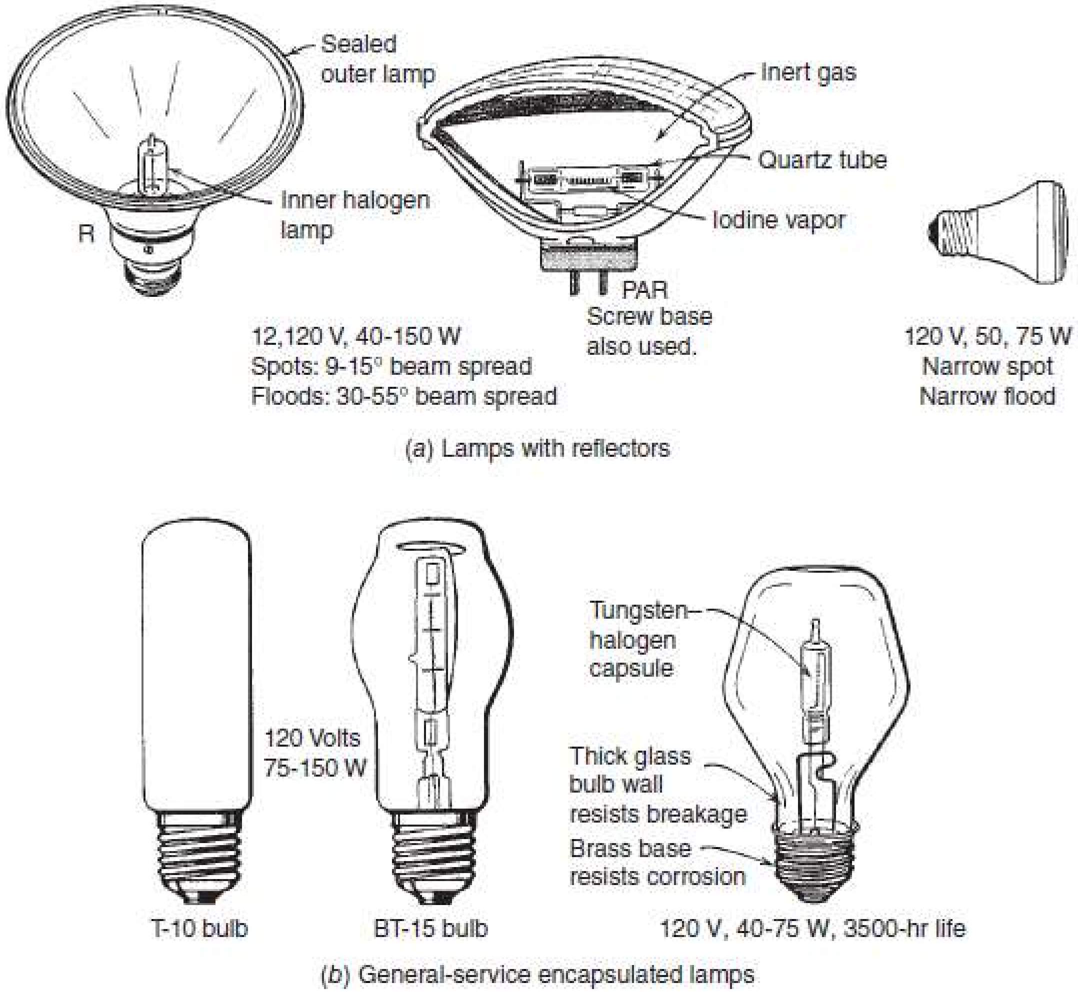


Fig. 15.4 *Tungsten-halogen lamps can be mounted in a variety of ways inside an enclosing glass envelope. (a) Lamp is used either horizontally or vertically to the reflector or (b) used without a reflector in a protective glass envelope and an Edison medium screw base.*

Fig. 15.5 *PAR halogen lamps with standard medium screw bases in sizes PAR 16, 20, 30, and 38 with a short or elongated lamp neck. Lamp wattages range from 45 to 90 W. (Courtesy of Philips Lighting Co.)*

MR-16 lamps

고온의 전구온도로 인해,
envelope이 하나 더 있음

(a)

FOOT CANDLE CONES

TRU-AIM TITAN™

10° NSP

Distance from Source (in ft.)	Diameter (in ft.)	Center FC 20W	35W	50W	65W
0′					
3′	0.5	556	922	1278	1556
6′	1.0	139	231	319	389
9′	1.6	62	102	142	173
12′	2.1	35	58	80	97
15′	2.6	22	37	51	62

25° NFL

Distance from Source (in ft.)	Diameter (in ft.)	Center FC 50W	65W
0′			
3′	1.3	356	444
6′	2.7	89	111
9′	4.0	40	49
12′	5.3	22	28
15′	6.7	14	18

40° FL

Distance from Source (in ft.)	Diameter (in ft.)	Center FC 20W	35W	50W	65W
0′					
3′	2.2	78	139	222	233
6′	4.4	19	35	56	58
9′	6.6	9	15	25	26
12′	8.7	5	9	14	15
15′	10.9	3	6	9	9

60° VWFL

Distance from Source (in ft.)	Diameter (in ft.)	Center FC 20W	35W	50W	65W
0′					
3′	3.5	39	72	111	117
6′	6.9	10	18	28	29
9′	10.4	4	8	12	13
12′	13.9	2	5	7	7
15′	17.3	2	3	4	5

(b)

Fig. 15.7 *Typical illumination cones for a MR-16 lamp. Abbreviations: NSP, narrow spot; NFL, narrow flood; FL, flood; VWFL, very wide flood. (Courtesy of Osram-Sylvania Products, Inc.)*

Gaseous discharge lamps

- Fluorescent and high intensity discharge (HID) lamps (mercury vapor, metal halide, high-pressure sodium)
- Lighting by producing an ionized gas in a glass tube rather than heating a filament
- Known for long lamp life and high efficacy
- All gaseous discharge lamps require a ballast

Ballasts (안정기)

- All gaseous discharge lamps require a ballast to trigger the lamp with a high ignition voltage and to control the amount of electric current for proper operation.
- Two kinds: magnetic, electronic, hybrid
- Primary functions
  - To supply the voltage to initiate starting
  - To supply the voltage and current to heat the electrodes (전극) to allow arc-mode (electric spark)
  - To supply enough voltage to maintain the arc during warmup and operation
  - To limit current once all the lamp components have reached equilibrium (방전이 시작되면 전류가 흐르기 시작하는데, 전류가 지나치게 증가하면 램프가 파괴될 수 있음. 이 때 안정기는 전류가 급격히 늘어나는 것을 막아줌)

Ballast characteristics: BF

- Ballast Factor (BF)
  - Defined as light output of a lamp operated on a test ballast / light output of the same lamp operated by a standard laboratory reference ballast (ANSI test procedure)
  - Ballast factor is the measured ability of a ballast to produce light from a connected lamp.
  - A ballast may have different ballast factors for different lamps.
  - Ballast factor is **not** a measure of energy efficiency.
    - A lamp with a low BF uses less energy, but light output is also less.
    - A lamp with a high BF uses more energy, but provides more light output.

Ballast characteristics: BEF

- Ballast Efficacy Factor = Ballast Efficiency Factor (BEF) = BF/ its input watts * 100
  - Expression of “lumen per watt for a given lamp-ballast combination”
  - BEF is generally used to compare the efficiency of various lighting systems.
  - A ballast with a ballast factor 0f 0.88 using 60 watts input power: BEF = 0.88/60*100 = 1.466
  - A ballast with a ballast factor 0f 0.82 using 60 watts input power: BEF = 0.82/60*100 = 1.366

Ballast types

- Three basic types: 자기식 (magnetic), 전자식(electronic), Hybrid

- Magnetic Core-and Coil Ballast (자기식 안정기)
  - It contains a magnetic core of several laminated steel plates wrapped with copper windings.
  - These ballasts have become essentially obsolete, although they are found in existing buildings.

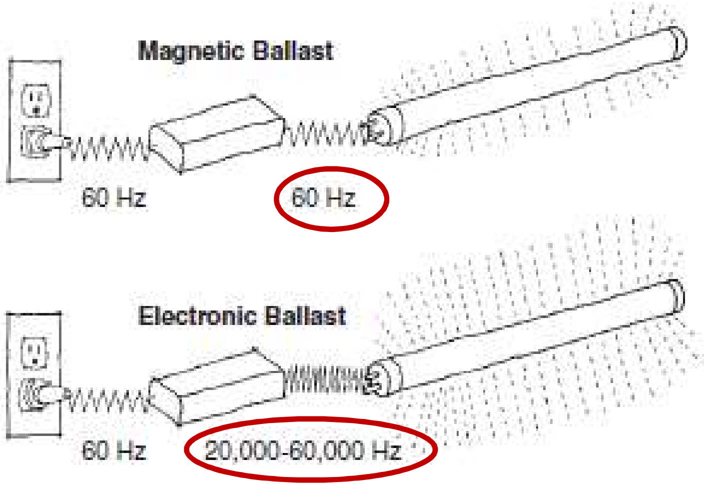


Fig. 15.8 *Ballasts for fluorescent lamps have traditionally been of the electromagnetic type, operating at a frequency of 60 Hz. Electronic ballasts operate at frequencies of 20,000–60,000 Hz and cause lighting systems to convert electric power to light more efficiently than systems run by electromagnetic ballasts. (Drawing by Jonathan Meendering; © Alison Kwok; all rights reserved.)*

Electronic Ballasts (전자식 안정기)

- Solid-state (반도체 기반의) electronic ballast operate lamps at 20–60 kHz and have less power loss than magnetic ballasts.
- Advantages: smaller, lighter, quieter, better lamp efficacy (10-15%), less heat, more energy-efficient, simplified dimming, reduced maintenance, silent
- Can be made small enough to be installed in CFL
- Comparison: two 40W T12 RS lamps
  - Magnetic consumes 100W, while electronic 90W
  - 10W reduction due to heat reduction in ballast.
- Electronic ballast is strongly recommended!!

Ballast Performance: heat

- Ballast heat is transferred to the luminaire body by direct metal-to-metal contact.
- Heat: at normal operating temperature, a ballast life of 12 to 15 years can be expected. Generally, ballast life is halved for every 50F° (27.8C°) above the standard 194°F (90°C) operating temperature, and, conversely, is doubled for every 50F° (27.8C°) reduction in operating temperature below 194°F (90°C).

Ballast performance: noise & flicker

- Noise: magnetic
  - Magnetic ballast operate at 60 Hz (AC).
  - A humming sound originates from the inherent magnetic action causing vibrations in the steel laminations of the core-and coil assembly.
  - Ballast noise becomes amplified because:
    - (1) of the method of mounting the ballast in the fixture
    - (2) of loose parts in the fixture
    - (3) ceilings, walls, floors and hard furniture reflect the noise
- Noise: electronic (most electronic ballasts make almost no sound.)
- Flicker
  - Magnetic: 120 times per second
  - Electronic: imperceptible

Special ballasts

- Low-current ballasts: intended to match specific low-current lamps, e.g. T8, slimline lamp, etc.
- High-current ballasts: intended to be used with High-Output (HO) lamps (increasing light output or reducing the number of fixtures).
  - General: 430 mA
  - >= 800 mA: high output (HO)
  - >= 1,500 mA (1.5A): Very high output (VHO)
- Energy saving ballasts: designed to reduce the total wattage (lamp + ballast)
  - by efficient design of the ballast itself
  - by the use of the lower wattage of the lamp itself
  - By disconnecting the lamp filaments after the lamp ignites.
- Multilevel ballasts: used to change lighting levels evenly (e.g. 0-50-100% or 0-33%-66%-100%)

Fluorescent lamps

- Introduced in 1937. replaced incandescent lamps in all fields except display and residential lighting.
- A cylindrical glass tube contains a mixture of an inert gas, generally argon, and low-pressure mercury vapor
- Phosphor coating
- 방전에 의해 자외선 (253nm) 발생, 방전관 내벽에 칠해진 형광도료를 자극하여 형광 발생 (형광체에 따라 다른 색을 발생)

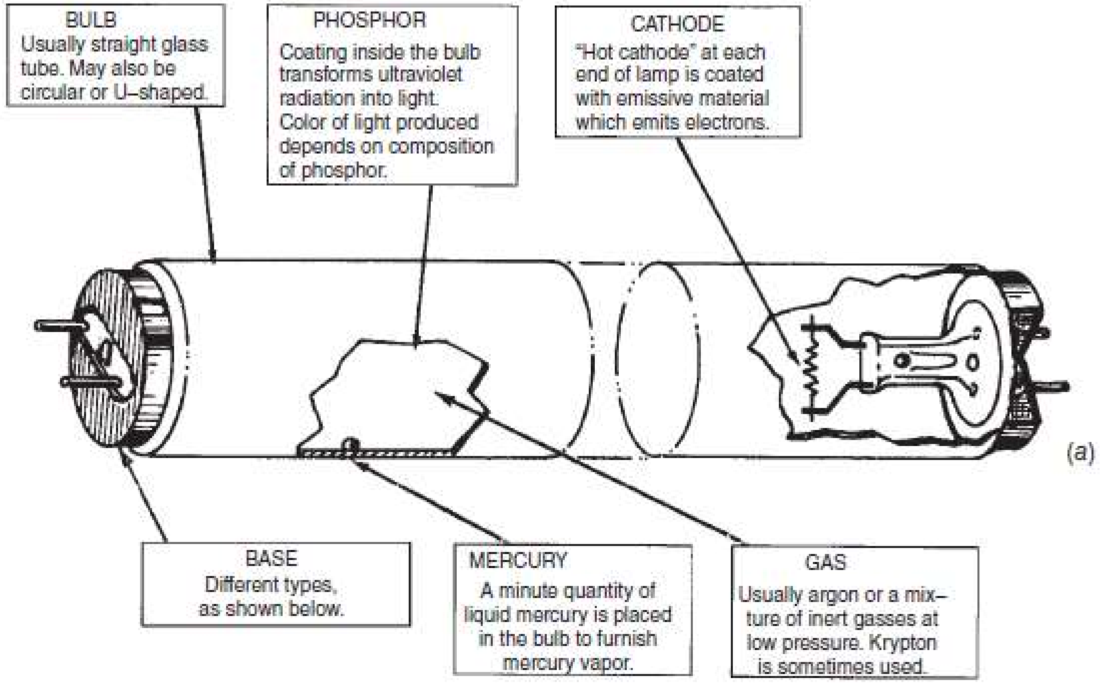


Fig. 15.9 Details of typical fluorescent lamps

Built into each end of the tube is a cathode that supplies the electrons to start and maintain an electric arc, or gaseous discharge.
→ Short-wave UV radiation, produced by the mercury arc, is absorbed by phosphors coating the inside of the tube, causing a reaction that emits visible radiation (light).

Fluorescent lamp construction

- Preheat lamp: 예열램프
  - The starter energizes the cathodes; after a 2 to 5 second delay, it initiates a high-voltage arc across the lamp, causing it to start.
  - No longer the industry standard!!
- RS [Rapid Start] lamps: 속시시동램프
  - The most popular fluorescent lamp.
  - No starter. The lamp's ballast constantly channels current through both electrodes, eliminating the delay inherent in a preheat circuit.
  - two pins at both ends
- Instant start lamp: 순간시동램프
  - single pin at each end

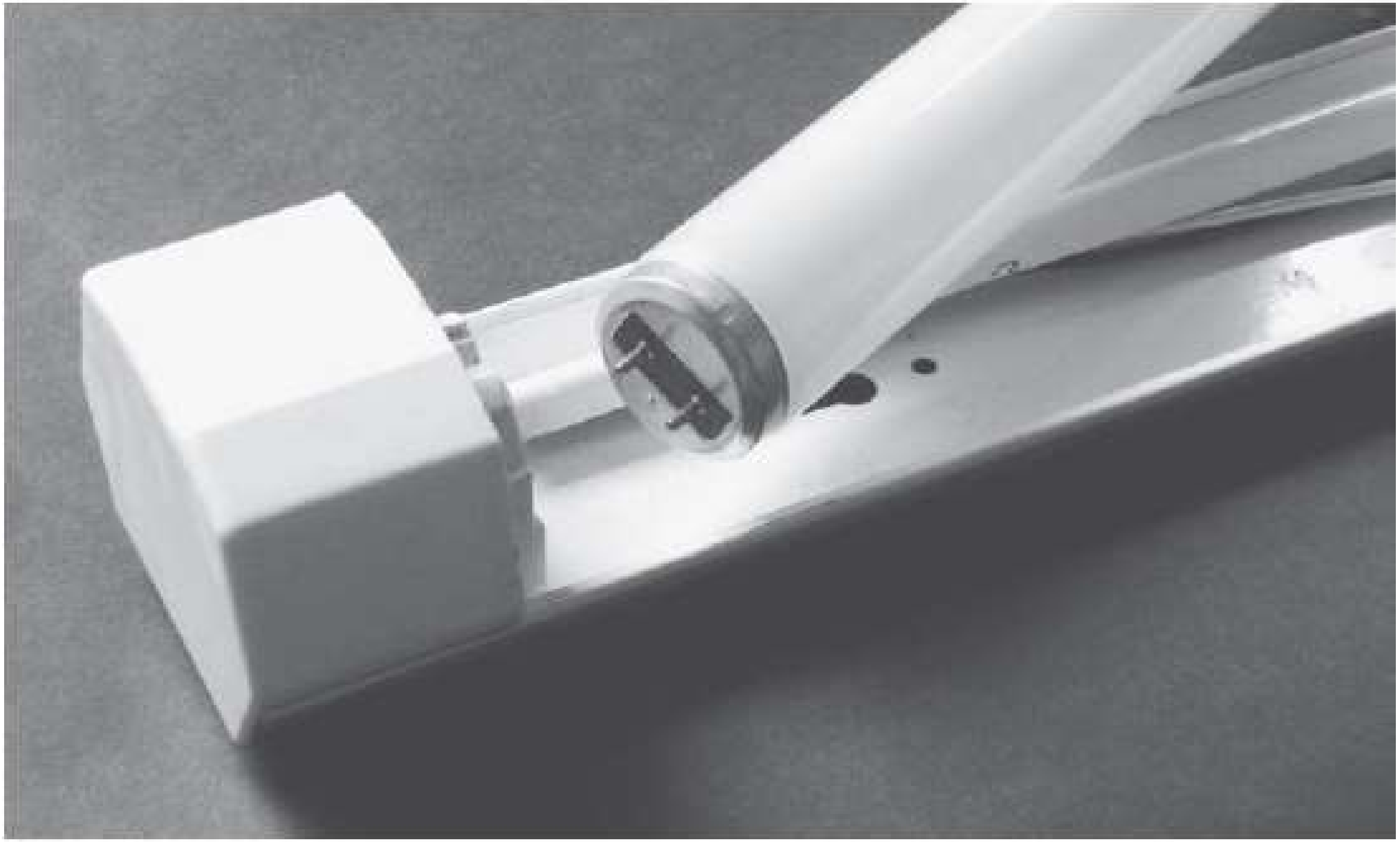


Fig. 15.10 Rapid-start fluorescent lamps have two pins that slide against two contact points in an electrical circuit. The ballast constantly channels current through both electrodes, creating a charge difference between the two electrodes and establishing a voltage across the tube. (Photo by Jonathan Meendering; © Alison Kwok; all rights reserved.)

Standard fluorescent lamp labels

- FSWWCCC-TDD
- F15CW-T12
  - F = Fluorescent
  - 15 = 15 Watt
  - CW=cool white
  - T = Tubular shaped bulb
  - 12 = 12/8” diameter

TABLE 15.3 Fluorescent Lamp Label Designations

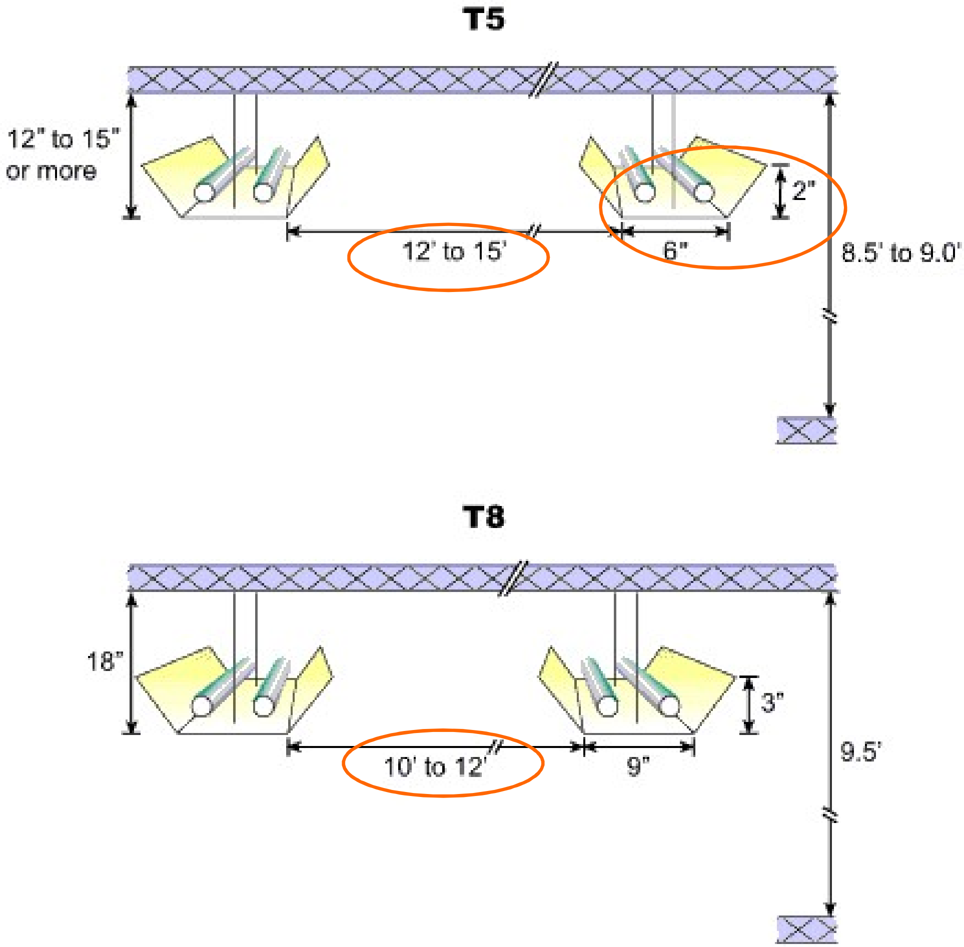
Label	Explanation
F	Fluorescent lamp. "G" means germicidal shortwave UV lamp.
S	Style—no letter indicates a normal straight tube; "C" means Circline.
W	Nominal power in watts: 4, 5, 8, 12, 15, 20, 30, 40, etc.
CCC	Color. W = white, CW = cool white, WW = warm white, BL/BLB = black light, etc.
T	Tubular bulb
DD	Diameter of tube in eighths of an inch. T8 is 1 in. (nominal 25 mm), T5 is ⅝ in. (nominal 15 mm), etc.

Fluorescent lamp types

- T8 fluorescent lamps
  - 1″ in diameter, length of 2′, 3′, 4′, 5′, CRI of 75-85
- T5 fluorescent lamps
  - 5/8″ in diameter, length of 22″, 34″, 46″, 58″, CRI of 85
  - T5 HO offers twice the maintained lumen output of a T8 lamp → fewer lamps, and fewer fixtures (less installation cost and maintenance, and more energy savings)
  - Potential for glare because of its smaller diameter
  - Due to its smaller diameter, the lamp can be concealed

T5 lamps

- Linear 5/8” diameter lamp
- Higher efficacy than T8
- Special lamp holder required due to the small size
- CRI: 80-85
- Surface luminance: 17,000 cd/m^2 for standard, 25,000-30,000 cd/m^2 for T5HO



T5 lamps increase options for indirect lighting (The high intensity and small size of T5 lamps enable their use in smaller fixtures that can be spaced closer to the ceiling, in rooms with lower ceilings, and farther apart than fixtures using T8 lamps)

Characteristics of fluorescent lamp operation

- Efficacy
- Lumen maintenance
- Lamp life
- Temperature and humidity
- Dimming

Efficacy

$$\text{luminous efficacy} = \frac{\text{lumens (light output)}}{\text{watts (power consumed including ballast losses)}}$$

$$= \text{lumens per watt (lm/W)}$$

- 40-85 lm/W (including ballast)
- For economic analysis: not only lm/W but also cost for fixtures, lamp replacement, etc. must be considered.

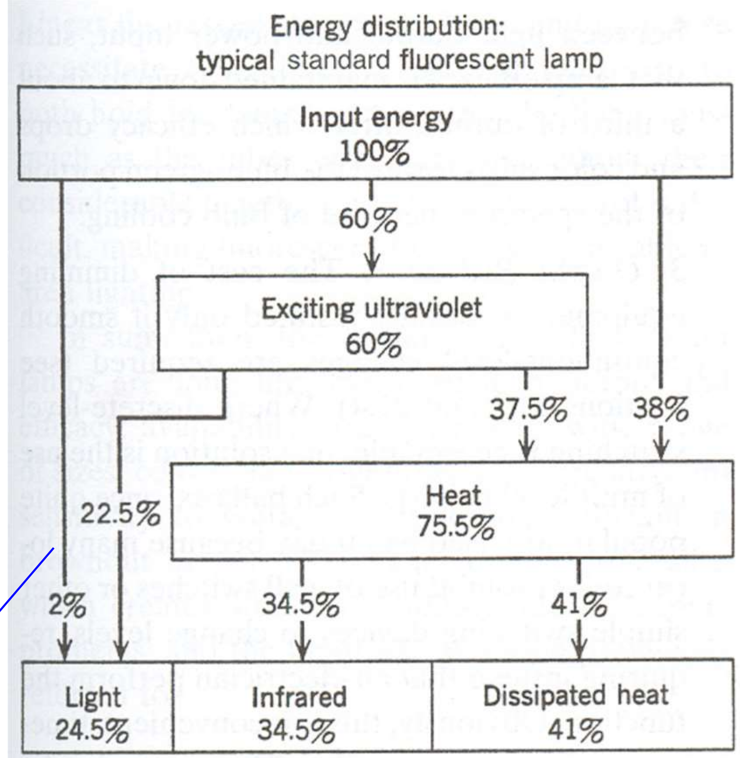


Fig. 19.52 Fluorescent lamps with efficacies of up to 85 lm/W are among the most efficient light sources available, yet still convert less than one-fourth of their energy to useful light. Ballast losses are not included in the percentages shown.

Image source: MEEB 9th Ed. (ballast loss not included)

고압 수은등 (high pressure mercury vapor)이 되면,
더 많은 비율의 가시광선이 발생함 → HID lamp

Lumen maintenance

- Lumen maintenance is an ability of a lamp to retain its lumen output over time.
- Lumen depreciation = the reduction of lumen output over time. (the opposite of lumen maintenance)
- Over time, phosphors deteriorate, typically blackening the ends of a lamp, thereby blocking some light. → generic lumen maintenance curve: refer to Fig. 14.11 (12th Ed.)
- Lumen maintenance is influenced by hours of operation (Fig. 14.11, 12th Ed.).
- Lumen maintenance is not affected by burning hours per start.
- The lumen output of a fluorescent tube decreases rapidly during the first 100 hours of burning.

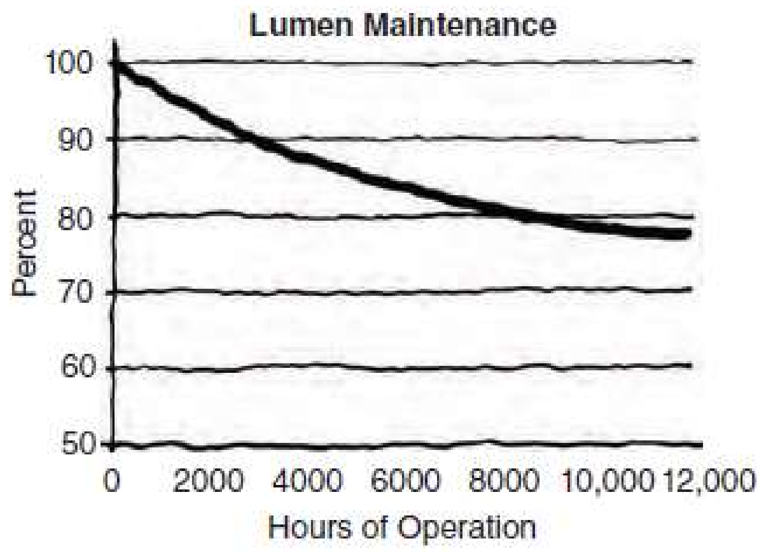


Fig. 14.11 *Generic lumen maintenance curve for fluorescent lamps; curve shows reduction in light output over time. Greater lumen maintenance means that a lamp will retain performance longer. The opposite of lumen maintenance is lumen depreciation, which represents the reduction of lumen output over time. (Drawing by Jonathan Meendering.)*

Image source: MEEB 12th Ed.

- Product catalog's initial lumens = lamp output after 100 hours
- Design or mean lumens = lamp output at 40% of rated lamp life

Lamp life

- Lamp life is dependent on burning hours per start!!
- Lamp life is based on a burning cycle of 3 hours per start (and 20 minutes of “off” status)
- Longer burning hours per start will extend lamp life.
- Lamp life can be shortened by improper voltage to the ballast or improper current to the lamp or improper cathode heating.

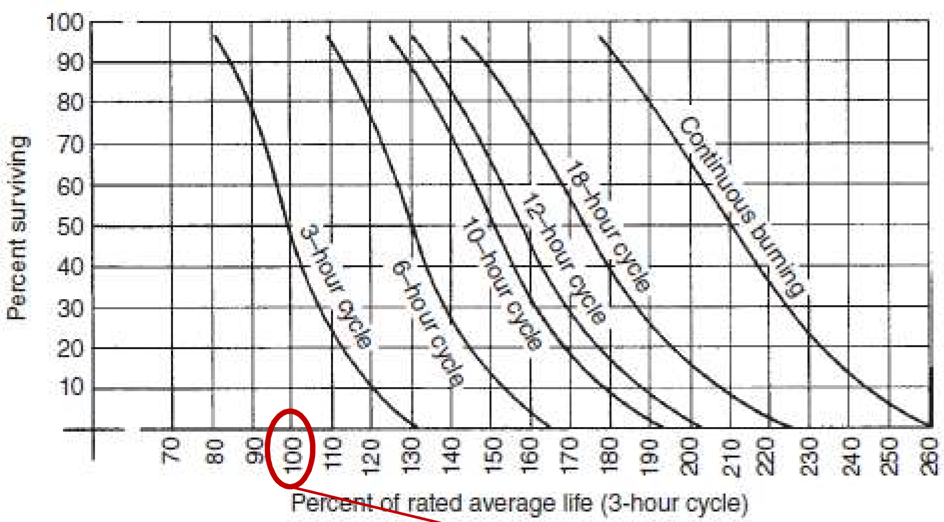


Fig. 15.11 *Typical mortality curves of standard fluorescent lamps.*

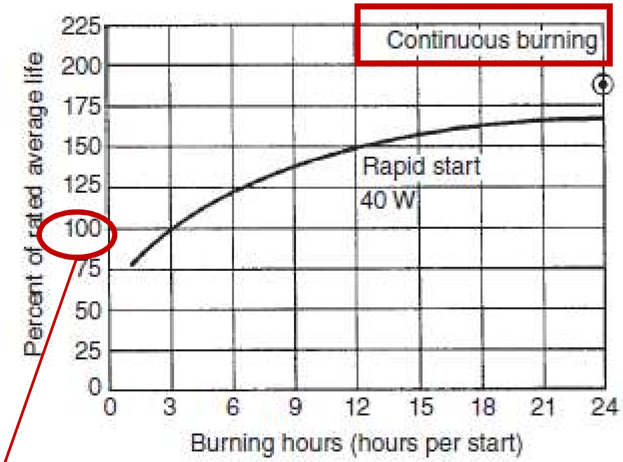


Fig. 15.12 *Effect of burning hours on fluorescent lamp life. Note that at 3 burning hours per start, the average lamp life is 100% of the nominal catalog value.*

100% of the nominal catalog value

Optimal switching problem (12^{th} Ed.)

- Energy viewpoint (lamp energy use) vs. resource viewpoint (lamp replacement cost)
- Variables
  - Lamp life reduction as a function of burning hours per cycle
  - Cost of energy
  - "Cost of lamp (part)" and "cost of lamp replacement (labor)"
  - Amount of time lamp remains off when shut off
  - Cost of switching equipment (if any)
  - Life of the building
- Given: 20-year fixture life, 8.5cent/kWh, 1.25$/lamp, 15 minutes relamping time, $8 per lamp switch per two 2-lamp fixtures, etc.
- Answer: lamps should be turned off any time they are not in use for 5 to 8 minutes more. (The range is caused primarily by variation in local labor rates.)
- It is thus clearly an economic fallacy to leave lamps burning to save money.

Effect of temperature and humidity

- Fluorescent lamps are affected by extremes in ambient temperature and by high humidity.
- Outside optimal operating temperature range: 5-25°C (outside of the range, a rapid drop in light output)
- Catalog data on lamp output: 25°C in still air
- High humidity causes electrical leakage along the lamp surface.
- The temperature of the wall of the lamp determines a lamp's mercury vapor pressure, which in turn determines the lamp lumen output.
- Maximum output for standard lamps occur at a bulb temperature of 40'C (104'F).
- Air return luminaires: cooling effect of the overheated lamp tubes → increase in efficiency

Dimming

- Dimming can reduce energy consumption, correct overlighting, balance indoor illuminance through integration with daylighting
- Unlike incandescent lamps, fluorescent lamps require dimming ballasts.
- With most dimming ballasts, output can vary between full and a minimum of about 10% of full output.
- Full range dimming: lamp output down to 1% of full lumen output (not recommended)
  - special dimming ballast required!!

Summary

- Advantages
  - long life, high output, high efficacy
  - availability in an extremely wide range of sizes, colors, and brightness
  - Low infrared output
- Disadvantages
  - Require ballast
  - Higher initial cost
  - large size (storage, handling, relamping): require bulky luminaires
  - Require special ballast to dim
  - Seriously affected by ambient temperature (changes in lumen output, energy use, light color)
  - relatively expensive luminaire
  - Lamp life dependent on burning hours per start: frequent on/off shortens lamp life.

UV F/L

- UV fluorescent lamps emit radiation in ultraviolet spectrum in the range of 10-400 nm.
  - UVA
    - 345-400nm: black light (causing many fluorescent objects to glow)
    - 315-345nm: sunning
  - UVB
    - 280-315nm: sunburn
  - UVC
    - 200-280nm: damaging biological cells. Used for germicidal purposes (in industry or for indoor air quality mitigation)

Triphosphor fluorescent lamps (삼파장 형광등)

- Standard fluorescent lamps: only one type of phosphor coating.
- Three different phosphors coating the inside of the tube [450nm(blue), 540nm(green), 610nm(red)] for good color rendering
- Improved CRI

Compact Fluorescent Lamps, CFL (소형 형광등) characteristics

- Unlike straight lone-tube type fluorescent lamps, CFL can replace incandescent lamps.
- simply folded fluorescent tubes with both ends terminating in a common base
- They can directly replace standard incandescent bulbs.
- CRI: 82, lamp life: 10,000-12,000 hours (a burning cycle of 3 hours per start)
- Not applicable to frequent short-duration use because the lamp life is strongly influenced by burning hours per start (closets, pantries, storage facilities)
- Ceiling down lights, desk lamps, decorative fixtures, 그 외 최소한 3시간 사용하는 곳에 적당
- Strongly influenced by temperature (output이 50%까지 감소)하므로, luminaire 안에 heat build-up이 되지 않도록 유의

Fig. 15.14 Collection of linear and compact fluorescent lamps (© University of Oregon, Baker Lighting Lab.)

screw base (alternative
to incandescent lamp)

Pin base

incandescent vs. CFL

- Table 15.4: equivalent wattage that provides similar light output.
- Table 15.5: cost comparison (assumptions: 8 cents/kwh for 6hrs/day)

TABLE 15.4 Equivalent Wattage of Common Incandescent Lamps and Compact Fluorescents

Incandescent Watts	Compact Fluorescent Watts
50	9
60	15
75	20
100	25
120	28
150	39

Source: U.S. Department of Energy, Energy Efficiency and Renewable Energy. http://apps1.eere.energy.gov/consumer/your_home/lighting_daylighting/index.cfm/mytopic=12060

(This comparison is made in terms of light output)

TABLE 15.5 Cost Comparison for Operation of an Incandescent Lamp and a Compact Fluorescent Lamp

	60W Traditional incandescent	15W CFL
Rated life (hours)	1000	10,000
Annual energy cost (@8¢/kWh for 6hrs/day)	\$4.80	\$1.20
Annual energy savings (%)	–	75%

Source: U.S. Department of Energy, How Energy-Efficient Light Bulbs Compare with Traditional Incandescents. https://www.energy.gov/energysaver/save-electricity-and-fuel/lighting-choices-save-you-money/how-energy-efficient-light

0.060 kw * 8 cents/kwh * 10,000 hours = 4.8$
0.015 kw * 8 cents/kwh * 10,000 hours = 1.2$

- http://www.youtube.com/watch?v=ODpK3WnzlQc
- http://www.youtube.com/watch?v=xB94OjTvtMk&feature=related

High Intensity Discharge (HID) Lamp (고광도 방전등)

- produce light by discharging electricity through a high-pressure vapor.
- high-efficacy, poor color rendering
- types:
  - Fluorescent: low pressure mercury vapor (HID에는 해당 안됨)
  - Mercury lamp (수은등, CRI: 15-55): high pressure mercury vapor
  - Metal-Halide lamp (CRI: 65-80): high pressure mercury vapor + addition of halides (thallium, indium, sodium)
  - High Pressure Sodium lamp (CRI: 22-75): high pressure sodium vapor
  - 고압이 되면, 자외선 뿐만 아니라, 가시광선도 발생함
- Applications: high illuminance over large areas, energy efficiency, long life are important (gymnasiums, high-bay industrial applications, large public areas, warehouses, outdoor activity areas, roadways, parking lots, pathways)

HID lamps

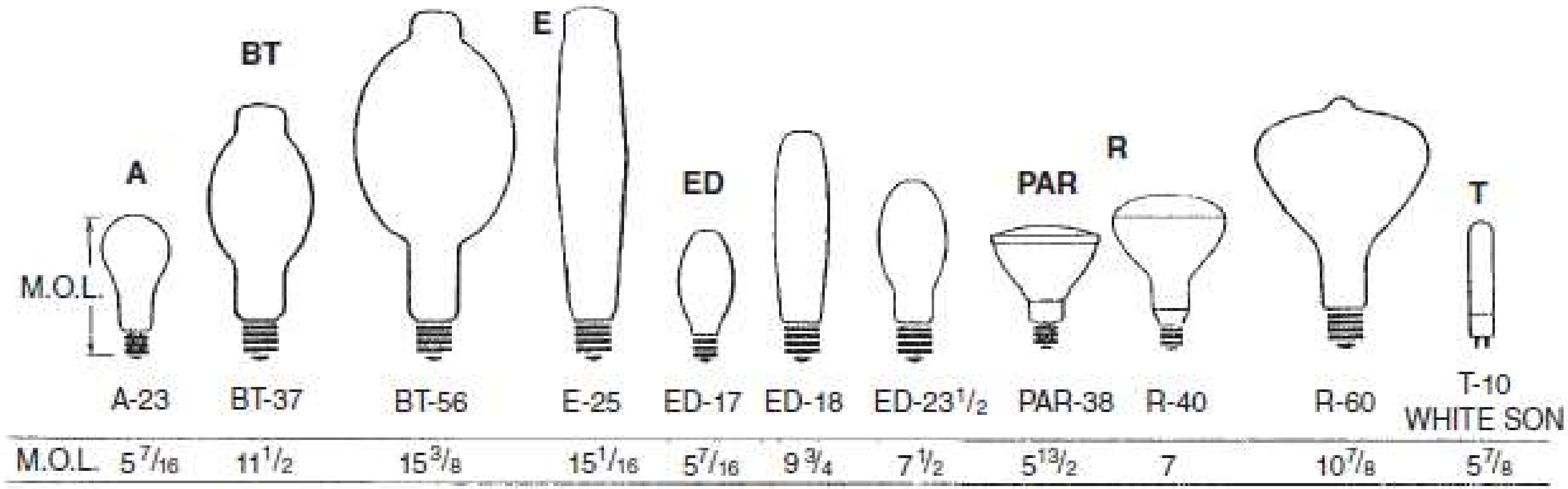


***Fig. 15.15** Bulb shapes for typical HID lamps with their maximum overall length (M.O.L.).*