

**48-410 Acoustics and Lighting
Fall 2008**

Monday, Wednesday, 12:30-13:20
DH A310 (lectures)
Hunt Lower Level (Software Sessions)

Lecture 3: Lighting Equipment

Course Instructor: Yi Chun Huang
yihuang@andrew.cmu.edu x-1492 MMCH Room 415 (IW)
Office Hours: Wed 18:00-19:00

Carnegie Mellon
Pittsburgh, Pennsylvania

Class Plan

- **Describing Color**
 - Color Temperature
 - Color Circle, HSV, Munsell, CIE
- **Light from electricity**
 - Types of lamps
 - Spectral Power Distribution, CRI
 - Polar Curves

References

The Design of Lighting. Tregenza, P. and D. Loe. E and FN Spon. 1998. Chapters 2,3 & 8.

Hyperphysics (©C.R. Nave, 2006) – Color & Color Vision.
<http://hyperphysics.phy-astr.gsu.edu/hbase/HFrame.html>

ERCO Guide - Design with colored light
http://www.ercos.com/guide_v2/guide_2/designing_w_90/design_wit_1822/en/en_design_wit_intro_1.htm

GE Lighting – Color Rendering
http://www.gelighting.com/na/business_lighting/education_resources/learn_about_light/color_rendering.htm

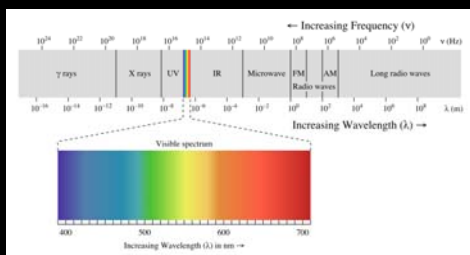
Color

Characterization of spectral distribution (intensities at various wavelengths) of electromagnetic radiation (electromagnetic model of light energy)

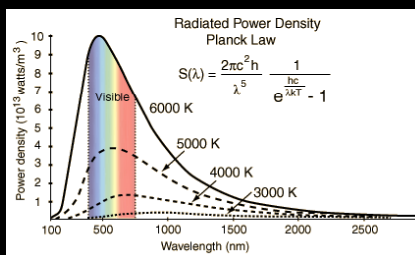
Visible Spectrum – approximately 380nm to 740nm (Spectral Colors)

Photometry (Human perception)

- The human eye is not equally sensitive to all wavelengths of visible light. i.e. different spectral combinations can give the same sensation
- Color Temperatures (warm/cool descriptors)
- Color Models/Spaces (CIE, HSV, Munsell System)



Visible Spectrum

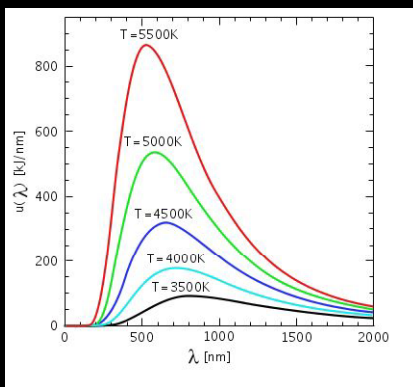


Spectral distribution of sunlight at 6000K - HyperPhysics

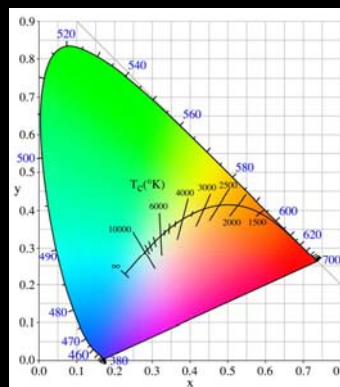
(Correlated) Color Temperature

Simplified way to characterize the spectral properties of a light source by comparing chromaticity of the light to an ideal black body radiator.

Temperature of heated black-body in degree Kelvins



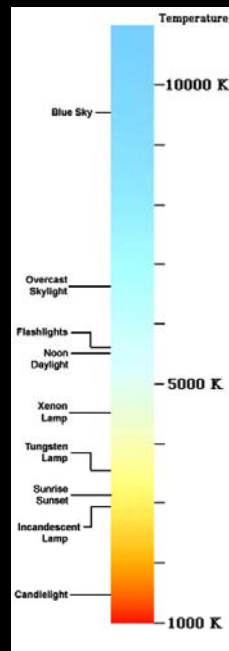
Black-body spectrum (Planck's Law)
Electromagnetic radiation from a black body at temperature T



Color Temperature line (at various temperatures) plotted on '31 CIE chromaticity space

(Correlated) Color Temperature

Color Temperatures of Common Light Sources	
Daylight Sources	Color Temperature (K)
Skylight	12000 to 18000
Overcast Sky	7000
Noon Sun / Clear Summer Sky	5000 to 7000
Noon Sun / Clear Winter Sky	5500 to 6000
Photographic Daylight	5500
Noon Sunlight (Date Dependent)	4900 to 5800
Average Noon Sunlight (Northern Hemisphere)	5400
Sunlight at 30-Degree Altitude	4500
Sunlight at 20-Degree Altitude	4000
Sunlight at 10-Degree Altitude	3500
Sunrise and Sunset	3000
Artificial Sources	Color Temperature (K)
White LED	6500 to 9500
Electronic Flash	5500 to 6500
Xenon Burner	6000
White Flame Carbon Arc	5000
Warm White Fluorescent Tubes (M2, S, & 2S)	4000
Aluminum-Filled Flash Bulbs	3800
500-Watt 3400 K Photoflood	3400
12 Volt/100 Watt Tungsten-Halogen @ 9 Volts	3200
12 Volt/50 Watt Tungsten-Halogen @ 9 Volts	3200
100-Watt Household Lamp	2900
40-Watt Household Lamp	2650
Gaslight	2000 to 2200
Candlelight (British Standard)	2900

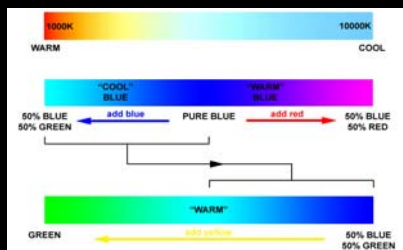


48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment

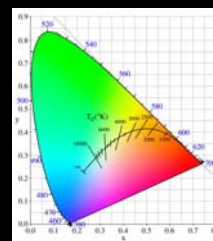
Carnegie Mellon

(Correlated) Color Temperature

Warm and Cool descriptors
 perceived effect, NOT Temperature
 (low K) Red → Warm
 (high K) Blue → Cool



- Cool light (3600-5500 K) produces higher contrast and is considered better for visual tasks.
- Warm light is more flattering to skin tones and is preferred for living spaces.
- 2700–3600 K range is recommended for most general indoor and task lighting.
- Cultural & personal bias.
- Paint colors are not spectral colors → thus “correlated”



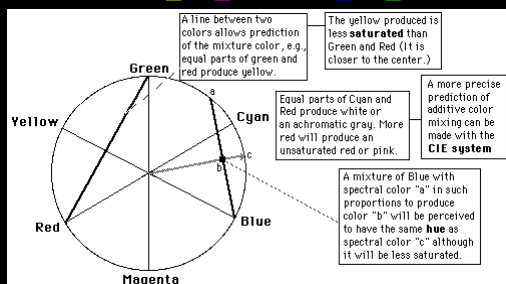
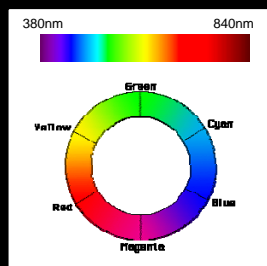
48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment

Carnegie Mellon

Color Circle, HSV, Munsell, CIE

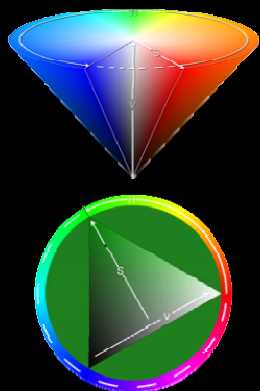
(Newton) Color Circle

Arranging spectral colors in a circle
(magenta is not spectral color)
Subtractive color mixing – primaries produce dark neutral



Color Circle, HSV, Munsell, CIE

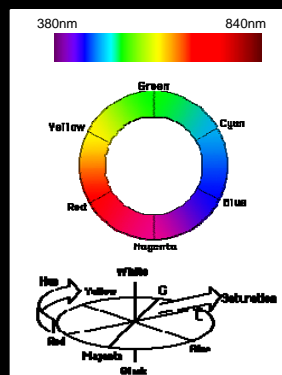
Hue, Saturation & Value



Hue
Spectral colors in a circle
hue refers to a pure color
(no tint or shade)

Saturation
Purity of color (hue)
Amount of pigment added

Value
Measure along light-dark axis



Color Circle, HSV, Munsell, CIE

Munsell System

Psychologically Ordered Color System

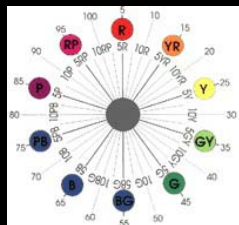
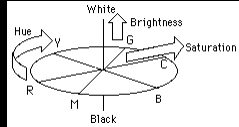
- modifies Newton Color Circle by dividing according to perceptible difference

10 basic hues, 10 basic values

Chroma (saturation) varies on ability of hue to be saturated at given value

- some hues have a wider perceived range, thus wider chroma range

Notation H V/C (eg. 5Y 8/0.5)



48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment



Color Circle, HSV, Munsell, CIE

1931 CIE Color Space (CIE xyY)

• Representation of all chromaticities visible to the average person (gamut of human vision)

• Mathematically defined model of describing color as tuples (chromaticity coordinates)

• 2 chromaticity coordinates (x,y) and a brightness parameter Y

Y = measure of brightness (luminance)

x = red

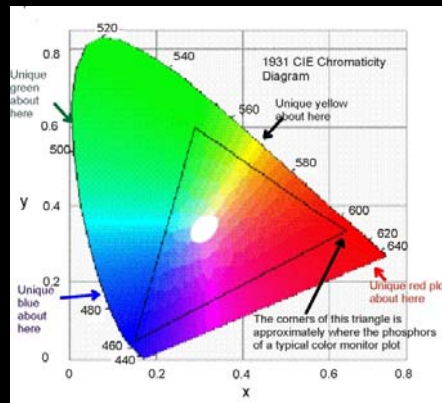
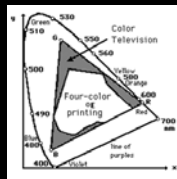
y = green

(1 - x - y) = blue

• Curved edge (spectral locus) corresponds to monochromatic light (Wavelengths in nanometers)

• Straight edge (line of purples) have no counterpart in monochromatic light

• No 3 or 4 color process can cover entire gamut



48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment



Types of Lamps

Lighting Design

- Ambient Lighting
- Accent Lighting
- Task Lighting
- Decorative Lighting

Electric Lamps

Incandescent, Discharge Lamps and LEDs

- Cost
- Luminous Flux
- Response times
- Direction
- Service Life
- Efficacy
- Color Rendering
- Brilliance
- Dimensions, durability, control gear, temperature ...



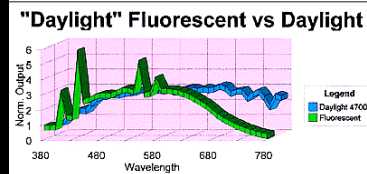
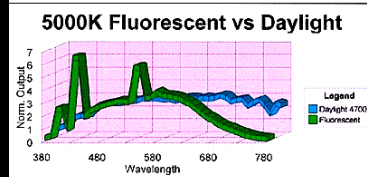
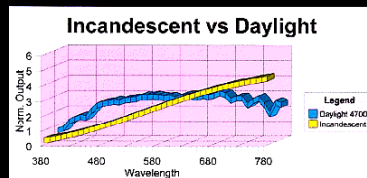
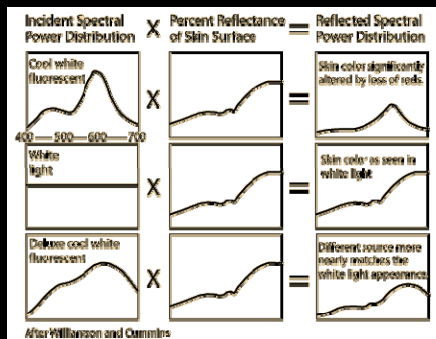
48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment

Carnegie Mellon

Spectral Distribution Curves

Graph of the spectral output from lamp

- affects color rendition
- may change over time (lumen maintenance)



48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment

Carnegie Mellon

CIE Color Rendering Index (CRI)

Effect of light source on color appearance of objects

Measures a lamp's coloring rendering using 8 standard colors

Ra 0 – 100

Incandescent lamp as reference (continuous spectrum)

> Ra 90 – accurate color matching

Ra 80 – 90 – accurate color judgment

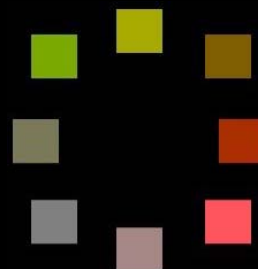
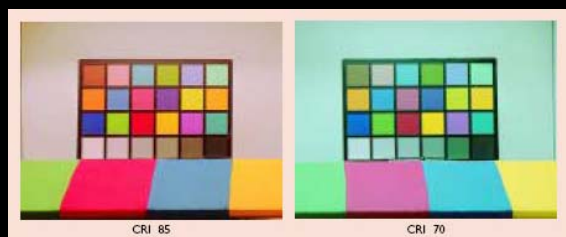
< Ra 80 – color quality of little importance

High CRI allows objects to appear more appealing and light level to be perceived brighter

Factories

Malls

Restaurants



48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment

Carnegie Mellon

Incandescent Lamps

Passing electric current to the extent it glows
(light energy from heat, recall black-body radiation)

Filaments and Gas

Low efficacy, radiant heat adds load to space cooling
1.5W – 300W (household 60–100W, >1000lm)

Tungsten with inert gas

Low cost but short life span ~1000 hours

Instant Start

Range of color temperatures 2800 – 5400K

Good Color Rendition Ra 100

Low efficacy 12 lm/W

Fully dimmable

Usually part of a luminaire, though no eqpt. required

Halogen Lamp

Low cost, life span 2000 hours

Quick Start

Color Temperature around 3000K

Good Color Rendition Ra 100

Directional, high brilliance

Low efficacy 30 lm/W

Fully dimmable

Low voltage versions require transformers



48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment

Carnegie Mellon

Discharge Lamps

Does not (typically) rely on material temperatures
 Photoluminescence and electroluminescence
 - absorption of high energy photons and emission of lower energy photons
 - emission of photons from excited molecules
 Discontinuous spectrum (dependent on material)
 Additional control equipment to generate initial high voltage to start discharge (might have noise)
 Additional equipment for dimming, if at all possible
 May require warm up time, color changes
 Typically longer lifespan (10-20x) and higher efficacy (5-10x), but higher cost

High Pressure

Metal Halide (Shops, sports, ~100 lm/W)
 High pressure sodium (Horticulture, exterior lighting, ~100lm/W)

Low Pressure discharge lamps

Fluorescent (Office, general applications ~100 lm/W)
 Low pressure sodium (Street lighting ~200 lm/W)



Metal Halide



High Pressure Sodium



Low Pressure Sodium



Fluorescent

48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment

Carnegie Mellon

Low Pressure Discharge Lamps

Fluorescent Lamps

Low cost, long life span 8000 hours
 Relative quick start and warmup (<3 sec)
 Range of color temperatures 2700 – 6500K
 Moderate Color Rendition Ra 80 - 85
 Efficacy 80-120 lm/W (lower at high and low temp)
 Usually not dimmable (expensive to implement)
 Requires ballasts (irritating hum)
 Flickering problems
 Phosphor and mercury – environmental & health issues



Low Pressure Sodium Lamps

Costly, long life span >15000 hours
 Slow warmup (7 – 15 min), instant restrike
 Color temperature 3000K
 Poor Color Rendition R_a 20 – 45
 Highest efficacy 200 lm/W
 Requires ballasts
 Has to be horizontal
 Better uniformity than most HID (High intensity Discharge) Lamps



48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment

Carnegie Mellon

High Pressure Discharge Lamps

Metal Halide Lamps

Low cost, long life span 10000 hours
 Relative quick start and warmup
 Crisp white light 4000K
 Good Color Rendition R_a 81 - 93
 Efficacy 100 lm/W, good maintenance
 Usually not dimmable (expensive to implement)
 Requires ballasts (irritating hum)



High Pressure Sodium Lamps

Costly, long life span 15000 - 24000 hours (> MH)
 Slow warmup (3 - 4 min), takes at least 1 min to restart
 Color temperature 2500K (< MH)
 Poor Color Rendition R_a 60
 High Efficacy 50-140 lm/W
 Requires ballasts



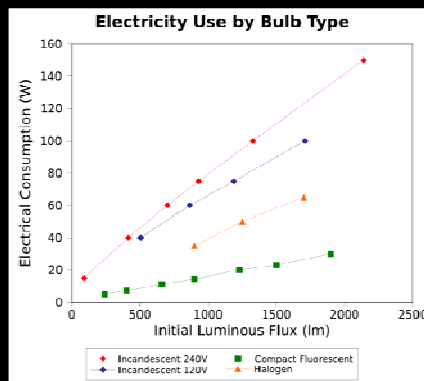
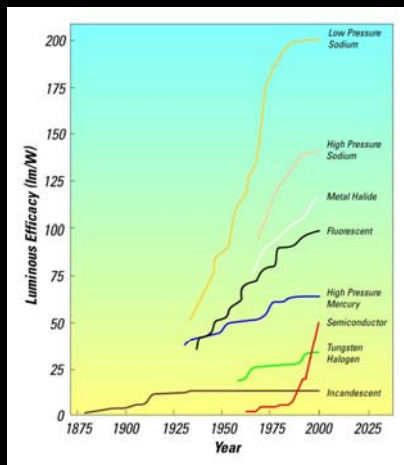
Lumen Output

Varies on type, wattage, technology

LED < Incandescent <= High pressure discharge <= Low pressure discharge

Characteristics	Lamp	Wattage Luminous flux	Characteristics	Lamp	Wattage Luminous flux	Characteristics	Lamp	Wattage Luminous flux
Floor washlight with LED		3.6 w/ 125 lm	Hi-bay Luminaire indirect lighting for fluorescent lamps		26 w/ 2900 lm	Jelly Spotlight with lamping base/adaptor for metal halide lamps		20 w/ 1650 lm
		3.6 w/ 90 lm			54 w/ 5000 lm			70 w/ 6600 lm
Jelly Floodlight for tungsten halogen lamps		150 w/ 2400 lm	Optec Wallwasher for compact fluorescent lamps		36 w/ 2900 lm	Parabole Pendant downlight for metal halide lamps		100 w/ 5800 lm
		150 w/ 2800 lm			55 w/ 4800 lm			100 w/ 5000 lm
		300 w/ 5950 lm				150 w/ 14000 lm		
		500 w/ 11100 lm						

Efficacies

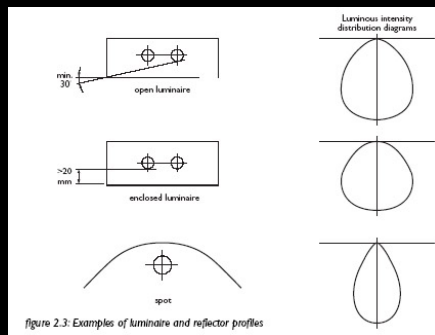


Lamps and Luminaires

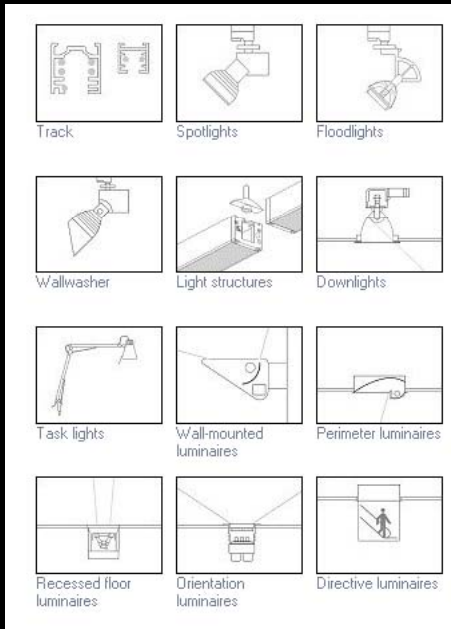
A luminaire is a complete lighting unit, including lamp, reflector, ballast, socket, wiring, diffuser, and housing

Redirecting Light

- Obstruction / Reflection / Refraction
- Control luminous intensity distribution
- Control Glare

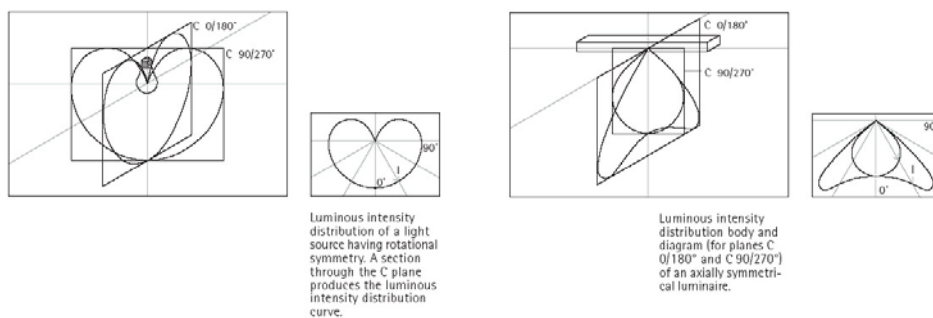


Types of Luminaires



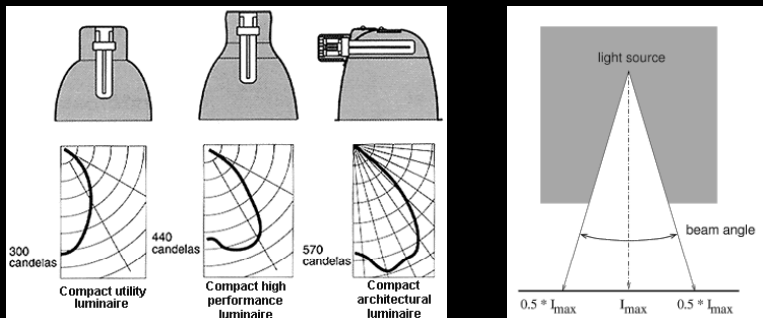
Polar Curves

Describes the luminous intensity distribution in space



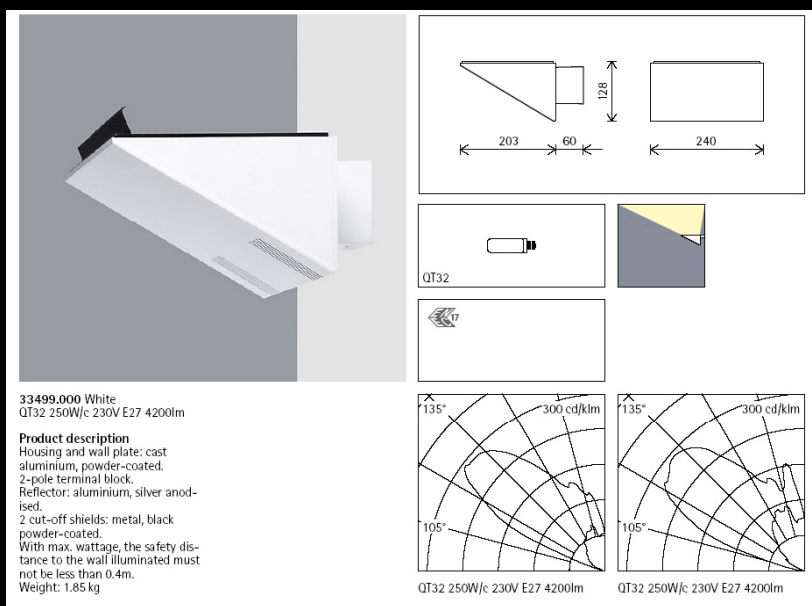
Polar Curves

- Beam Spread (0.5 of max luminous intensity)
- Cut off angle



48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment

Carnegie Mellon



48-410 Acoustics and Lighting – Lecture 3 Lighting Equipment

Carnegie Mellon