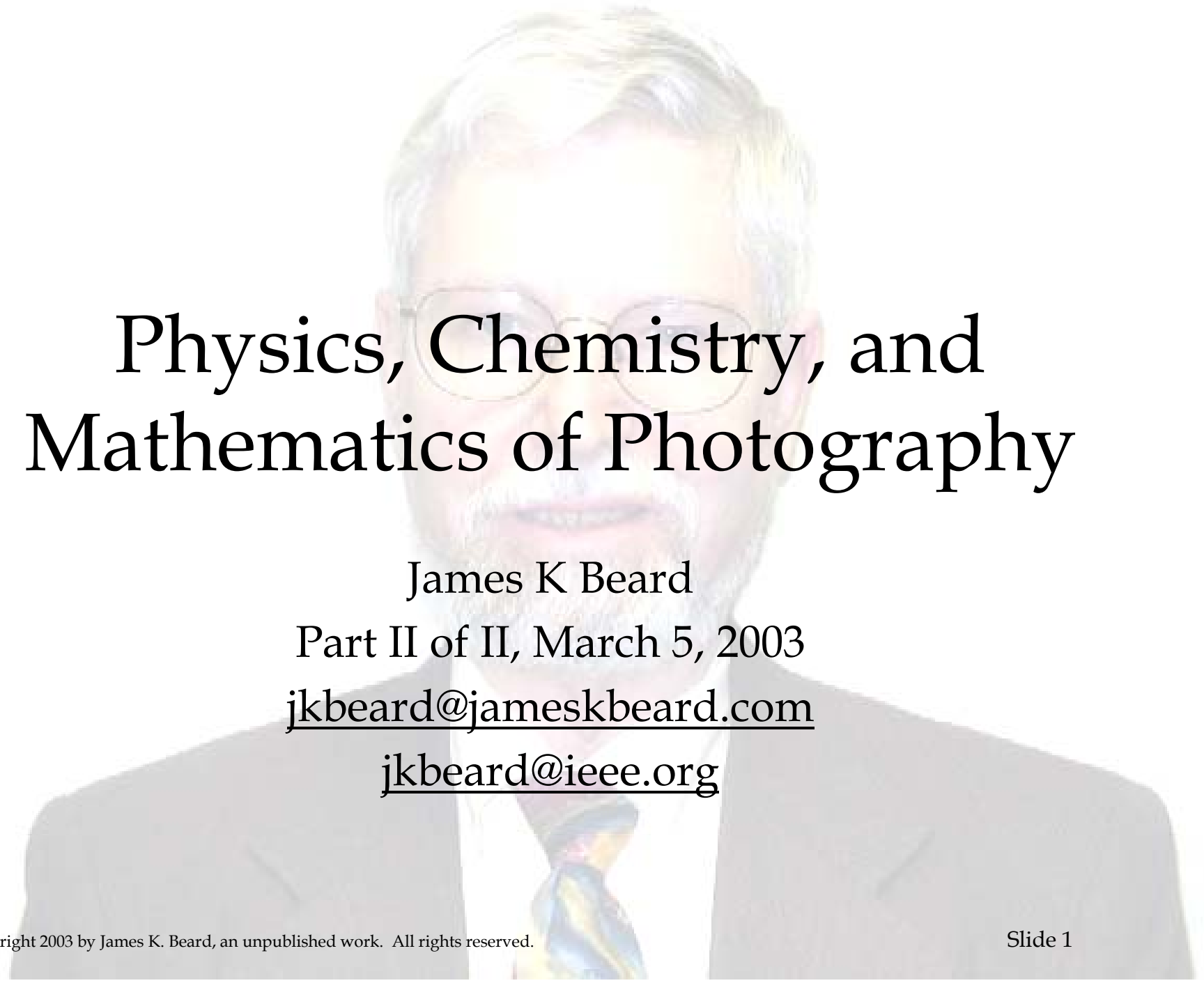

Physics, Chemistry, and Mathematics of Photography

James K Beard

Part II of II, March 5, 2003

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Topics

- Part I: Resolution
  - On the film
  - On the print
  - On the slides
  - In television
- Part II: Color, shading, and prints
  - Contrast, color, and the Zone System
  - Lens design
  - Digital and conventional photography
  - The portal: scanning and scanners

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Negative Films

- Black and white
  - Film contrast is about 0.7
  - Standard print paper contrast is about 1.4
  - Special paper contrasts vary from about 0.5 to 2.5 for solving special problems
- Color negatives have a standard
  - Film contrast is 0.5
  - Paper contrast is 2.0

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Color Negative Film

- Print quality is the requirement
- Problems are
  - Spectral sensitivity of the layers to pure blue, green, and red
  - Spectral purity of the dyes for yellow, magenta, and cyan
- Design is
  - Allow a color cast (the familiar orange)
  - Accept a low contrast in the negative

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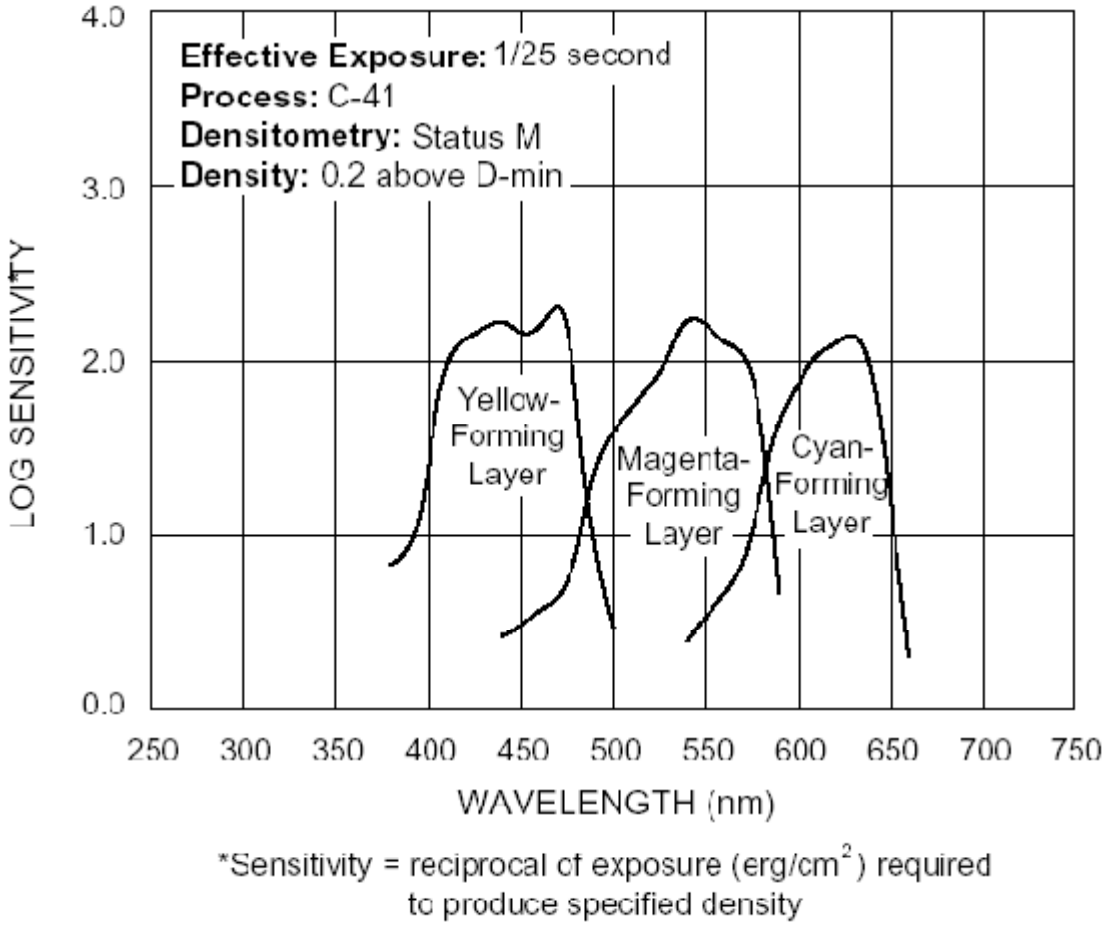
Spectral Sensitivity Curves



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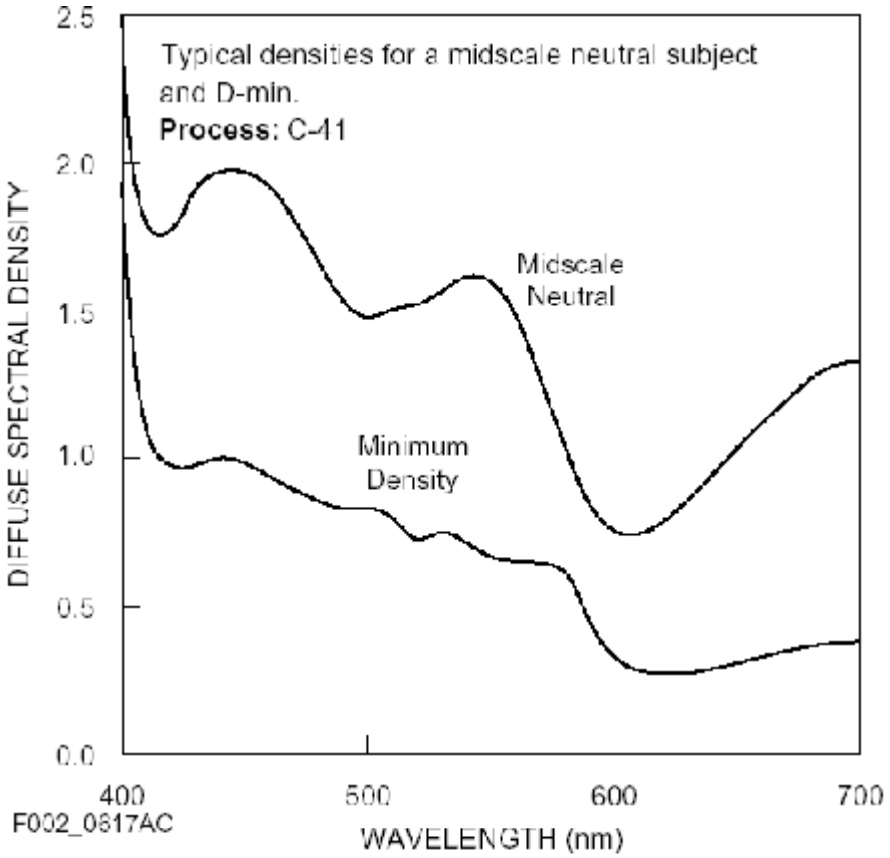
Spectral Dye Density Curves



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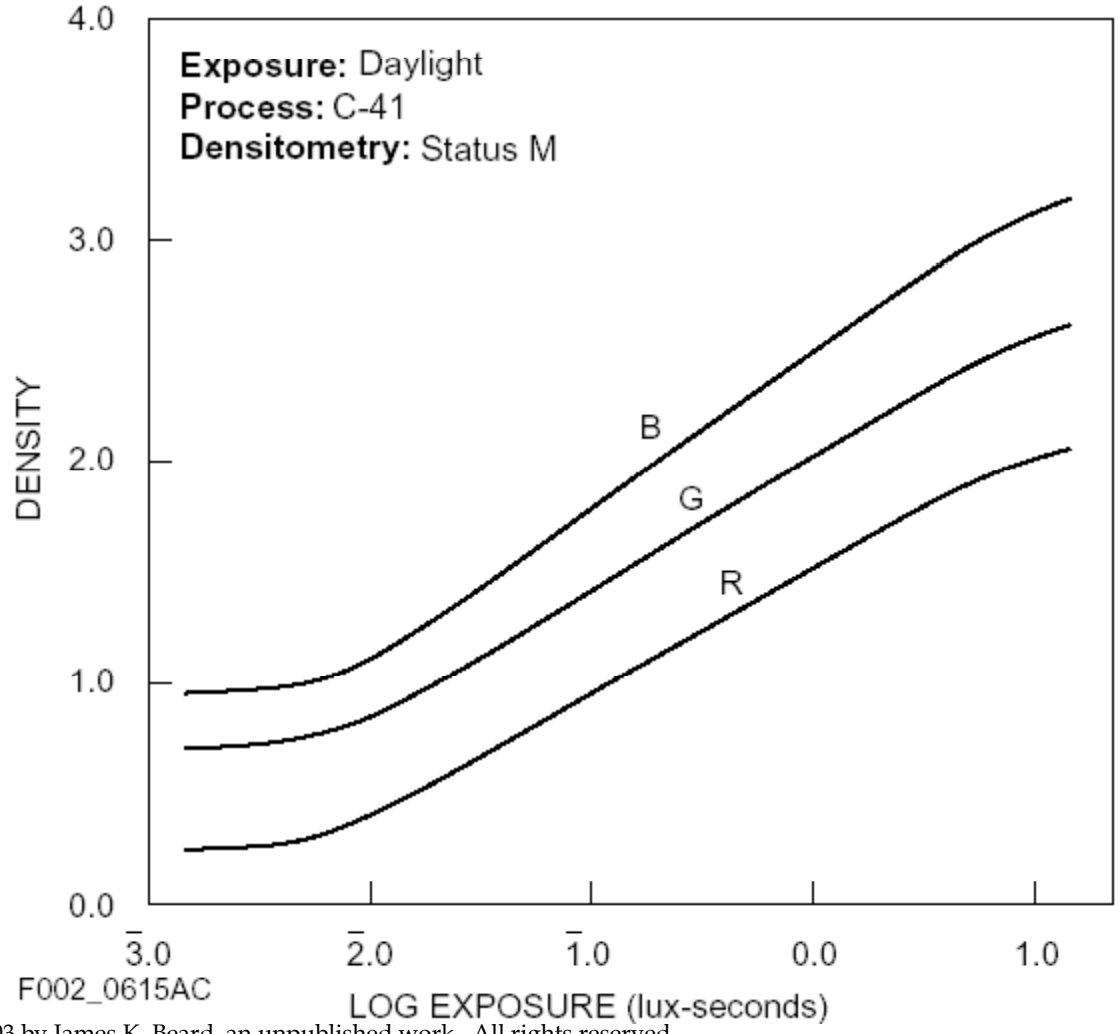
Characteristic Curves



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Print Paper and Color Slides

- Special requirements
  - Highlights must be clear to be white or project brightly
  - Overall color cast must be neutral
  - Contrast must be near 1.0
- Color slide film Contrast is about 1.1
- Prints
  - Reversal paper contrast is about 1.0
  - Color print paper contrast is about 2.0

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The Trade Space

- Dynamic range limits
  - Dye density range is the image dynamic range
  - Density range of 1.8 is minimum for high quality prints and slides
- Resolution versus speed
  - High speed needs thicker emulsion
  - Thicker emulsion means lower resolution
- Grain is the noise floor for resolution

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Quality and the Trade Space: Color Negatives

- Quality is the only objective
- Trade space issues
  - Color purity
    - » In the color-sensitive layers
    - » In the dyes formed in the development process
  - Grain, sensitivity, and resolution
- Results
  - High quality color
  - Good speed, fine grain, high resolution with technology advances

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Quality and the Trade Space: Prints From Color Negatives

- Objectives
  - Quality
  - Bright whites and dark blacks
- Trade space issues
  - Color purity in sensitivity and dyes
  - Consistent color balance from black to white
- Results
  - High quality color
  - Speed-grain trade available to consumer

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Quality and the Trade Space: Color Slides

- Objectives
  - Quality
  - Transparent whites
  - Dark blacks
- Problems are
  - Color purity in sensitivity and dyes
  - Grain, sensitivity, and resolution
- Results
  - Good to excellent quality color
  - Highest speeds, good grain, good resolution

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Quality and the Trade Space: Prints From Color Slides

- Objectives
  - Quality
  - White whites
  - Dark blacks
- Problems are
  - Color purity in sensitivity and dyes
  - Grain, sensitivity, and resolution
- Results
  - Good quality color
  - Different character than prints from negatives

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Color and Digital Photography

- Color Purity
  - Light recording – Limited only by filtration quality, a trade with "film speed"
  - Digital output – unlimited, cross-color coupling in sensitivity is reduced with software
- Linearity
  - Essentially perfect, limited by electrical leakages
  - Bounded
    - » Below by shot noise
    - » Above by saturation

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Problems in Digital Photography

- Resolution
  - Focal plane pixel count – limited by CCD gate density
  - Each pixel is only one color – resolution is 1/3 that indicated by focal plane pixel count
  - Exception – emerging Foveon technology
- Color
  - Dyes in photo printers are the limitation
  - Dye design simpler than film and paper dyes
- Exposure latitude

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When Smaller Is Better

- Smaller focal plane
  - Trade space for lens is friendlier
  - Faster lenses for given performance
  - Wider zoom range for given performance
  - Higher resolution for given speed
- Digital photography
  - Smaller focal planes, better lenses at present
  - Focal planes are getting bigger
  - An experimental 21 MPX focal plane is bigger than a 35 mm image

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Lens Design

- Goal: Make optical distance to a flat focal plane equal across the aperture
- A curve fitting problem in these variables
  - Wavelengths 0.4 to 0.7 microns
  - Angle of incidence == position on the focal plane
  - Object distance (conjugate)
  - Zoom
- Solution must be near optimal at all useful f/stops

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The Lens Trade Space

- Diffraction limited resolution is the goal
- Goals are ¼ wavelength variation in effective optical length of collimated light to a point on the focal plane
- Variables in the curve fitting problem
- Reflections and flare
- Optical absorption in the glass

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Examples of Lenses

- Single wavelength, single point, single conjugate diffraction limiting
  - Single element
  - Any glass
  - Aspherical lens surfaces for fast lens
- Two wavelength – achromats
  - Two elements
  - Glasses with different dispersion (crown, flint)
- Three wavelengths – apochromats

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Lens Aberrations

- Blooming
  - Difference in focal plane distance with distance from center of lens
  - Occurs anywhere on image plane
- Astigmatism
  - Difference in focal length and focal plane distance with position on lens plane
  - Occurs off-axis
- Coma
  - Difference in focal length with position on image plane

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Lens Distortions

- Pincushion – focal length shorter off-axis
- Barrel – focal length longer off-axis
  - Fish-eye effect is intentional barrel distortion
- Focal plane curvature
  - The main fit parameter in the lens design problem
  - Sometimes intentionally done to match film curvature
- Fish-eye lenses
  - Originally conceived for comet searches
  - Stereographic projection equalizes exposure over the focal plane – no cosine falloff

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Lens Technologies

- Lower dispersion glasses
  - Achromat trade space friendlier
  - Achromat performance similar to apochromats
- Aspherical lens surfaces
  - Faster high-quality lenses
- Multiple layer coatings
  - Lower reflections over spectrum – less flare, lower light loss
  - Less coloration in transmitted light

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Focal Plane Size

- Larger focal plane
  - Longer focal lengths for equivalent coverage
  - Larger lens surfaces with ¼ wavelength tolerances
  - Volume of glass proportional to cube of focal plane width
- Result of reducing focal plane size
  - More variety in lenses
  - Faster lenses
  - Wider zoom ranges

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The Zone System

- A Zone is
  - A one-stop (factor of two) variation in exposure
  - A measure of brightness in the scene
  - A measure of brightness in the print
- Zones
  - Zone I is total blackness
  - Zone VIII is total whiteness
  - Print zones are II to VII
  - Mid-range is Zone V

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8-Bit Digital Zones

Zone	Value	Example
VII	128 – 255	White, with detail
VI	64 – 127	Sky, bright colors
V	32 – 63	Mid-tones
IV	16 – 31	Darker colors
III	8 – 15	Shadows, with color
II	0 – 7	Black, with detail

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Scanning and Originals

- Prints from negatives or slides
  - Highlights and shadows flattened by the characteristic curve of the paper dyes
  - Loss of color fidelity through imperfect sensitivity and density curves
  - Changes in color balance with zone
- Color slides
  - No flattening of contrast in shadows
  - Otherwise, same problems as prints
- Color negatives – color balance changes with zone

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Conclusions

- Conventional photography
  - Here to stay for awhile in niche applications
  - The vacuum tube technology analogy
- Digital photography
  - Still an emerging technology
  - Just now really competitive with conventional techniques
  - Superior potential for color fidelity, resolution, cost
  - Extremely large prints impractical just now
- Scan the negative or slide if available

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