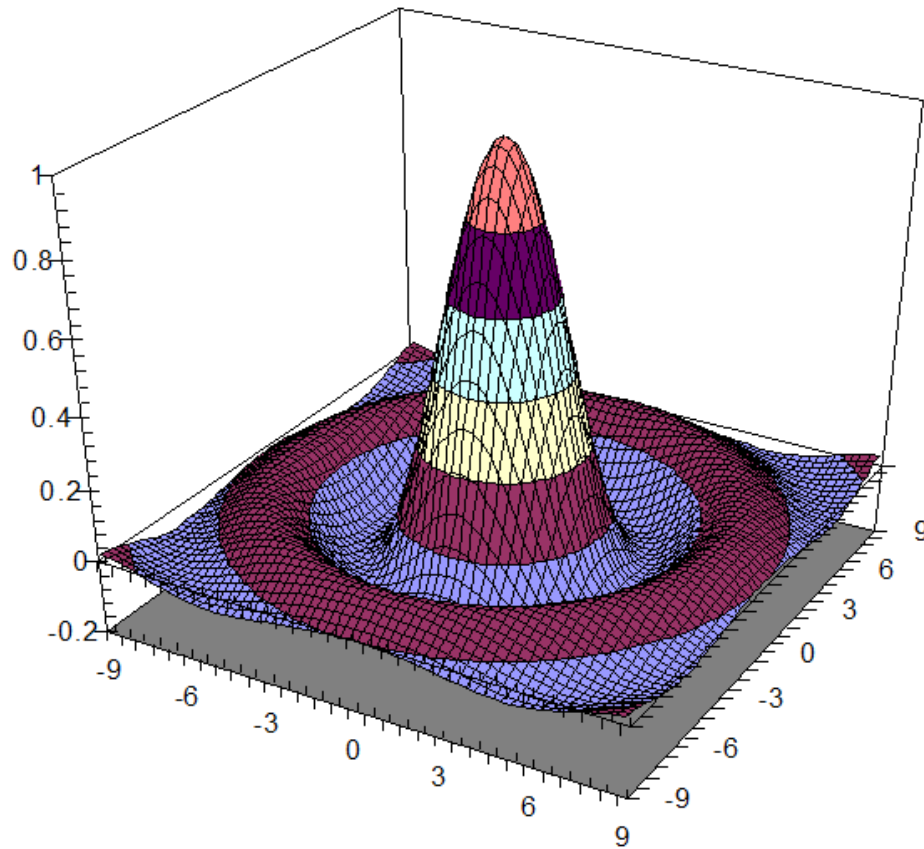


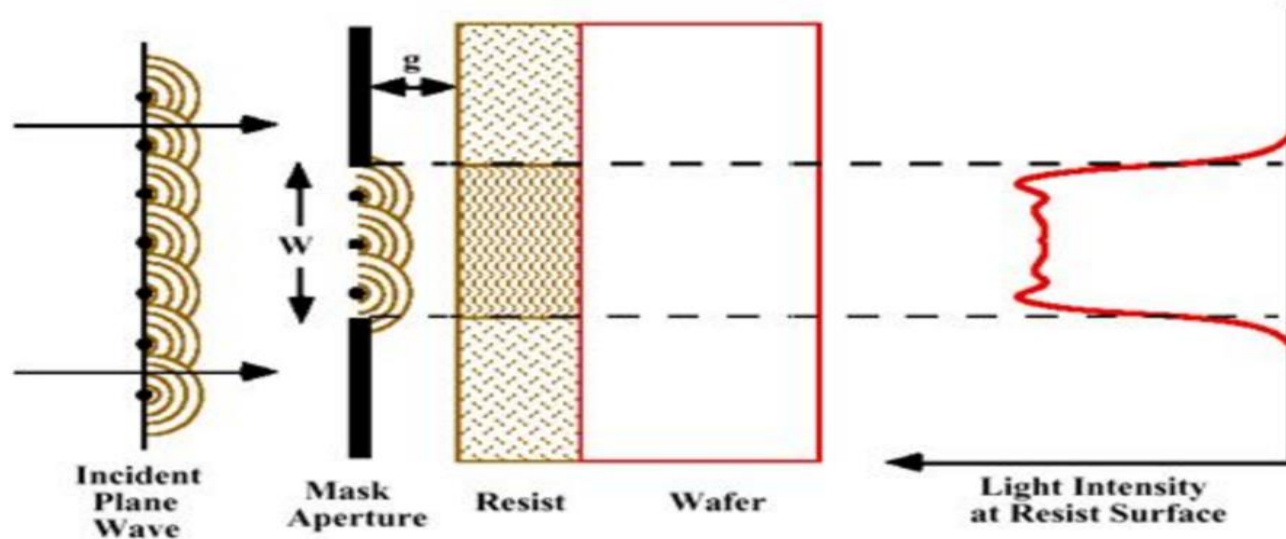
Lecture 4

Chemical Engineering for Micro/Nano Fabrication



Fresnel Diffraction in Proximity Printing

Near field or Fresnel Diffraction Regime When $g < W^2/\lambda$



- Image can be constructed from point sources of spherical wavelets in the opening (Huygens' Theory)
- There is interference between these waves that causes “ringing”
- Here the minimum feature size is $W \sim \sqrt{\lambda g}$
- For $g = 20 \mu\text{m}$ and 365 nm light, W is on the order of $2.7 \mu\text{m}$

- [Wavelets](#)

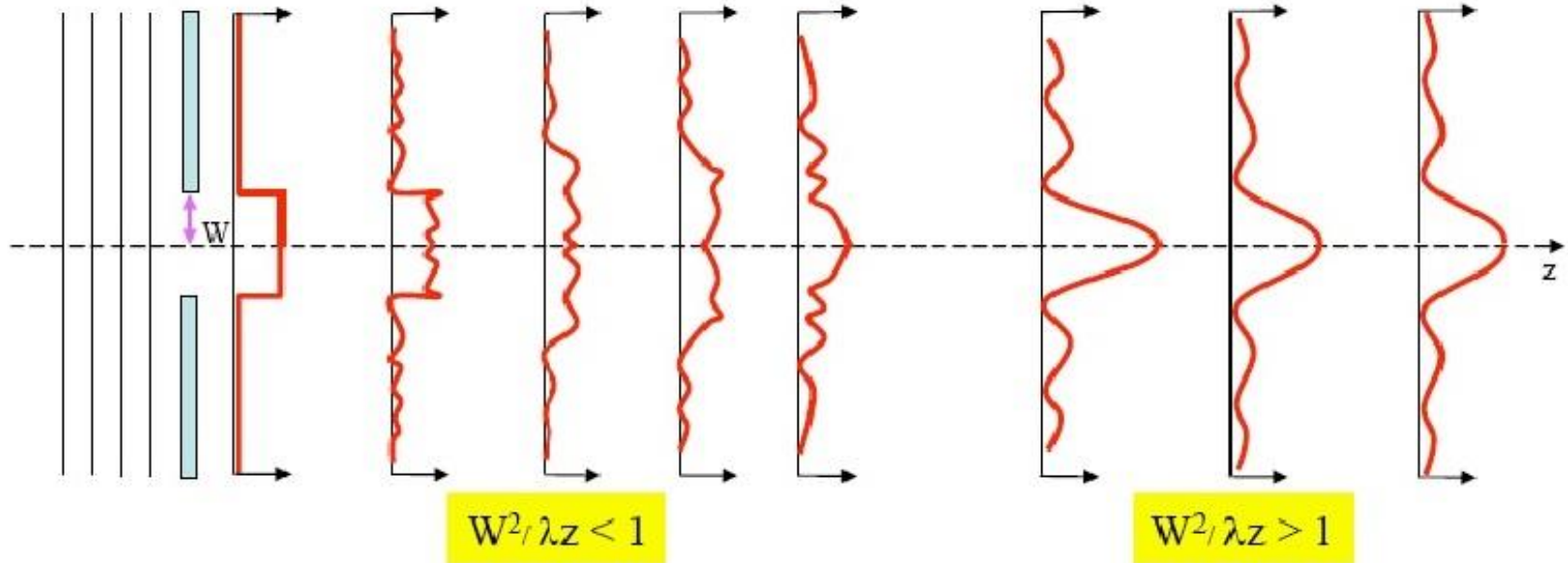


Now we have Fraunhofer Diffraction

Far Field Diffraction.

Near Field (Fresnel) Diffraction

Far Field (Fraunhofer) Diffraction



Brief Look at Fraunhofer Diffraction

Some Excellent Video Lessons

<https://www.youtube.com/watch?v=blur0MemUQA>

Constructive and destructive Interference

<https://www.youtube.com/watch?v=PgW7qaOZD0U>

Single slit diffraction demonstration

<https://www.youtube.com/watch?v=7CmbItRjM-Y>

Single Slit Diffraction

<https://www.youtube.com/watch?v=luv6hY6zsd0>

Double slit waves 2:00

<https://www.youtube.com/watch?v=nuaHY5lj2AA>

Double Slit Demonstration

<https://www.youtube.com/watch?v=Pk6s2OIKzKQ>

Double slit Diffraction – Part 1

<https://www.youtube.com/watch?v=1abpdO27KTo>

Double Slit Diffraction - Part 2



Resolution Limit of the Photolithographic Process

Theoretical Resolution

$$F = k_1 \frac{\lambda}{NA}$$

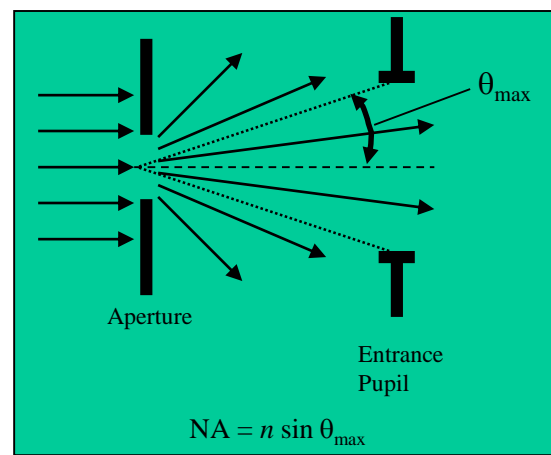
F : Minimum feature size

λ : Exposure wavelength

k_1 : Process-dependent factor

NA : Numerical aperture of lens system

n : Index of refraction (for air, $n \approx 1$)



Feature size is directly related to the **wavelength** of the exposure radiation



Rayleigh's Rule



John William Strutt, third Baron Rayleigh

1842-1919

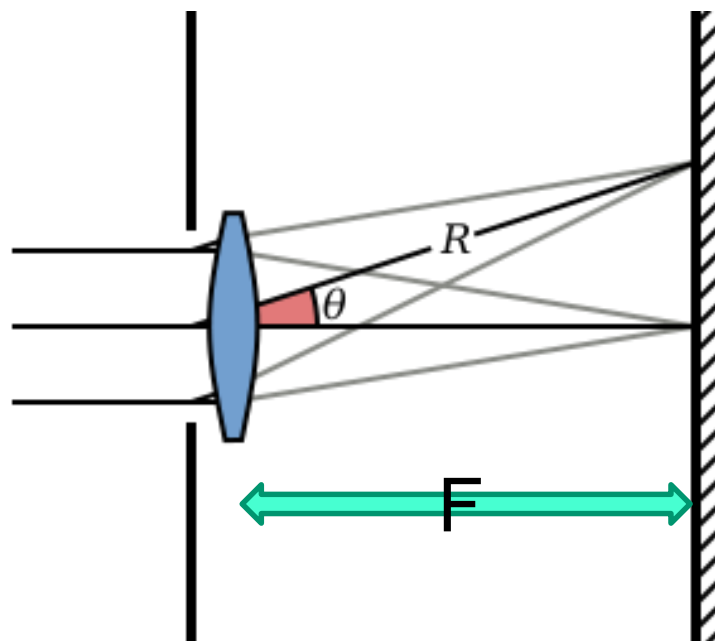
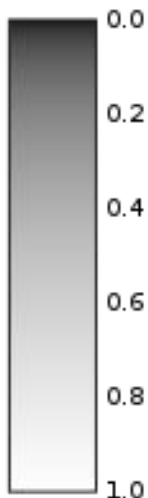
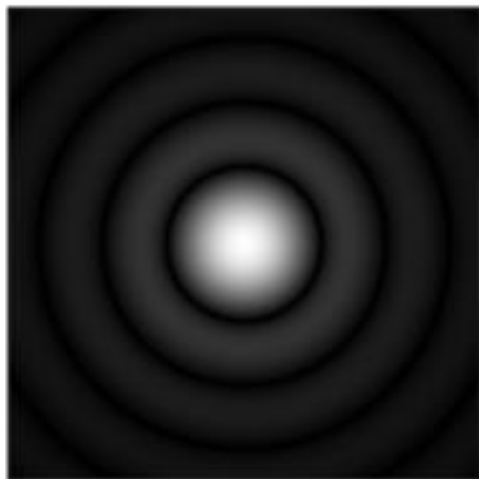
The Nobel Prize in Physics 1904

$$R = k_1 \frac{\lambda}{n \sin \theta}$$



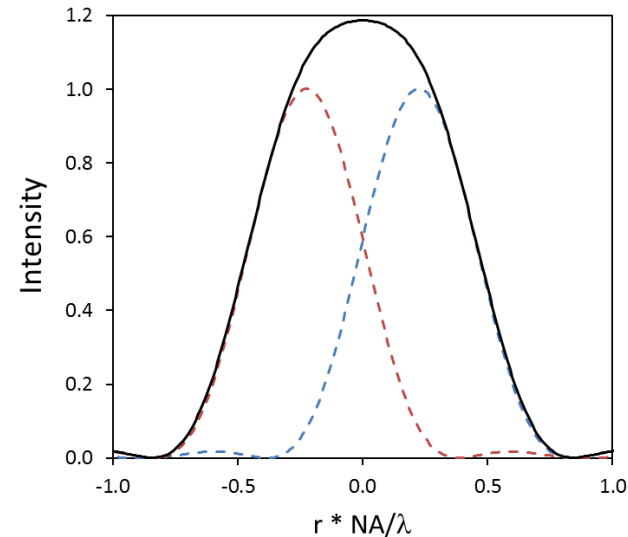
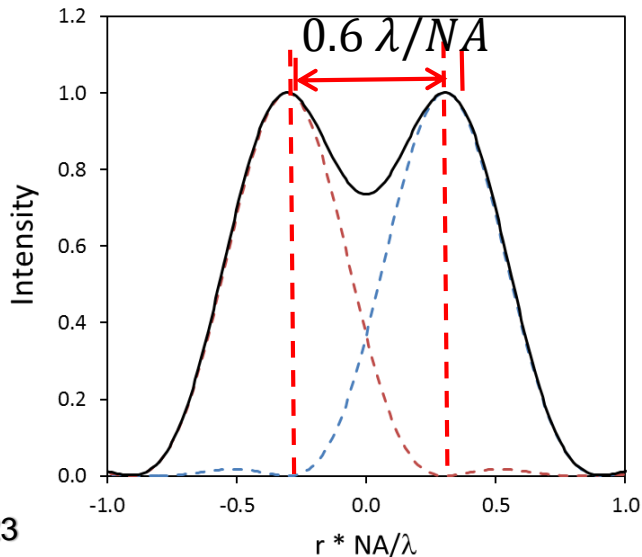
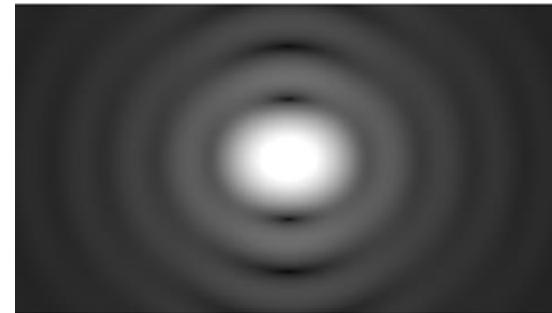
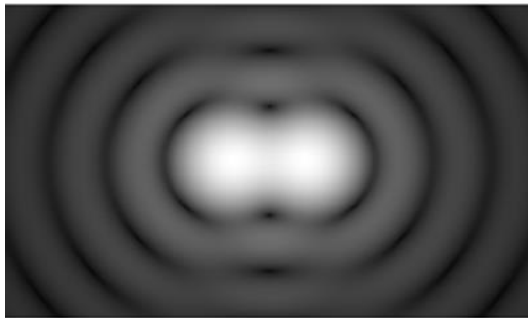
Sir George Airy

Airy disk is a description of the best focused spot of light that a perfect lens with a circular aperture can make



Rayleigh's Rule for Resolution

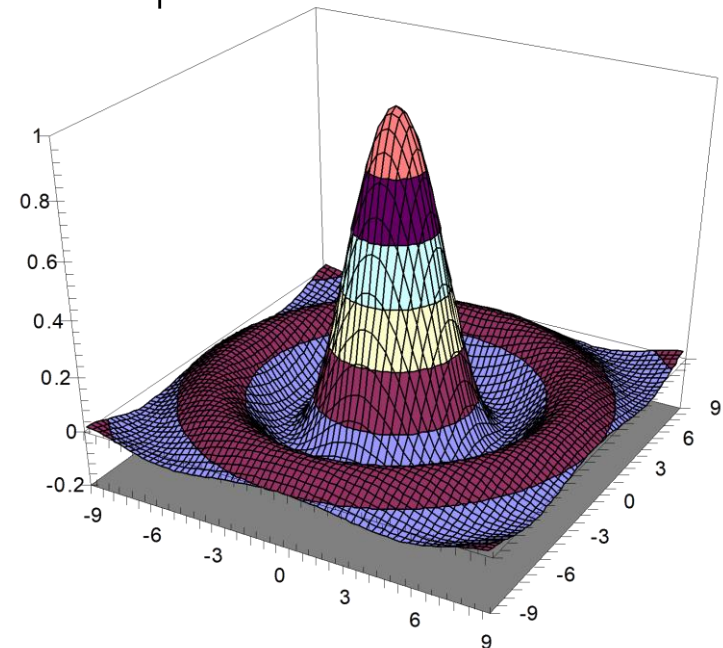
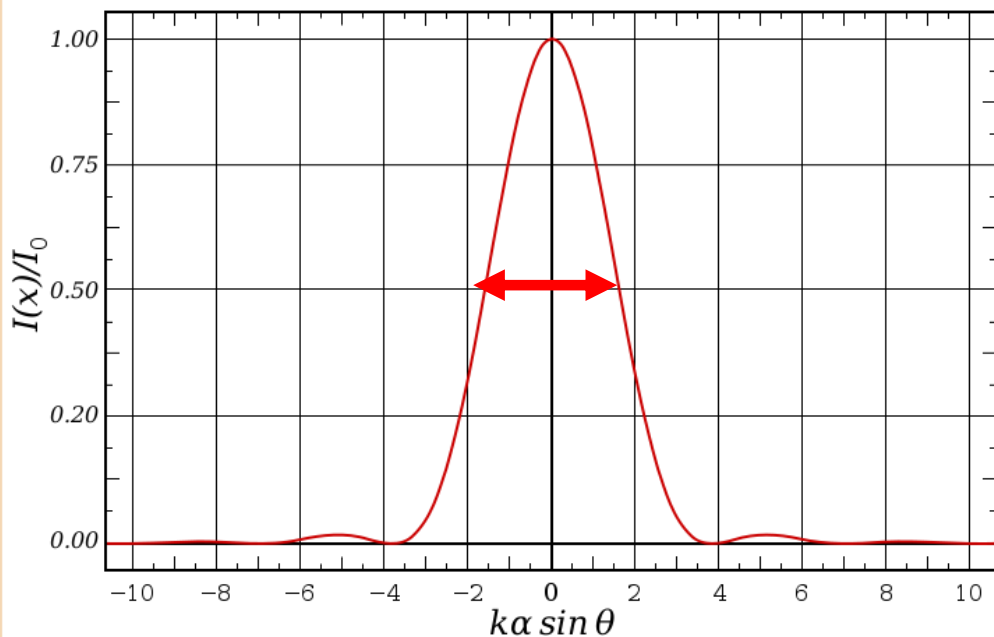
Lord Rayleigh defined this criterion: when the first minimum of one Airy disk coincides with the maximum of another $\rightarrow 0.6 \lambda/NA$



Defining the resolution of an imaging system

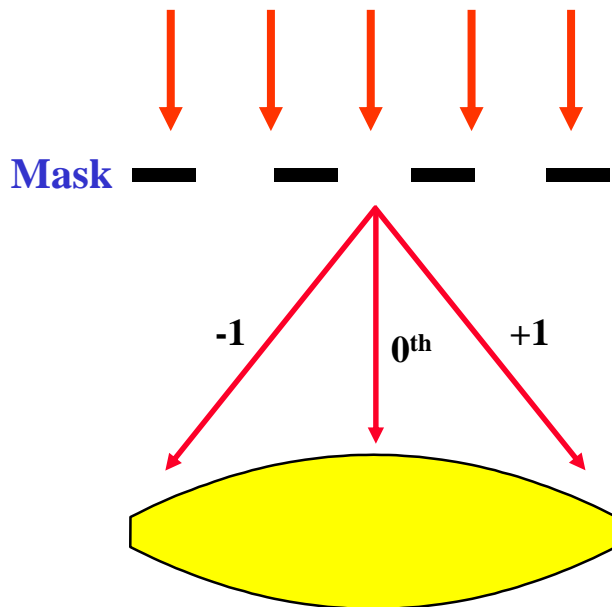
- When a single point of light is imaged it becomes the point spread function (PSF) of the lens system.
 - For an ideal, circular imaging system, the PSF is called the Airy disk:
 - The FWHM of the Airy disk is $0.5 \lambda/NA$, which defines the smallest image of a point source

$$PSF = \left| J_1(2\pi r NA / \lambda) / \pi r \right|^2$$



Lithography breaks Rayleigh's rule

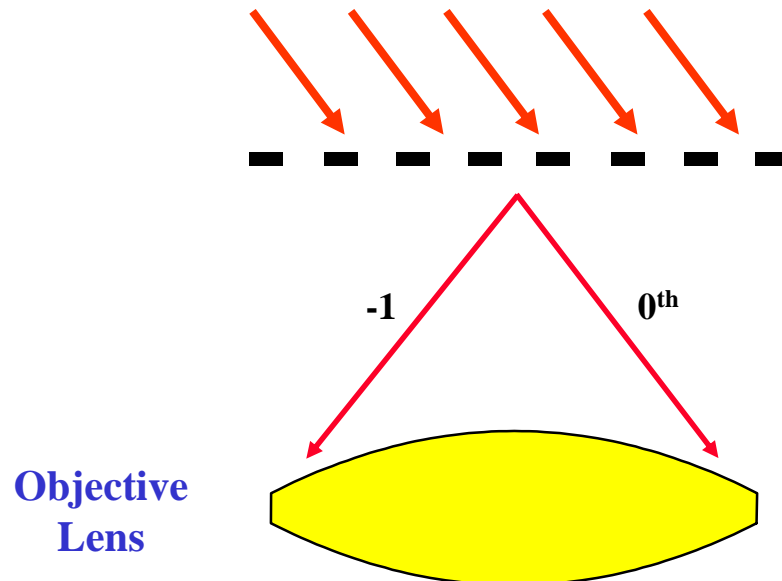
Normal Incidence



$$\sin \theta_{max} = NA = \lambda/p_{min}$$

$$R = \frac{p_{min}}{2} = 0.5 \frac{\lambda}{NA}$$

Oblique Incidence

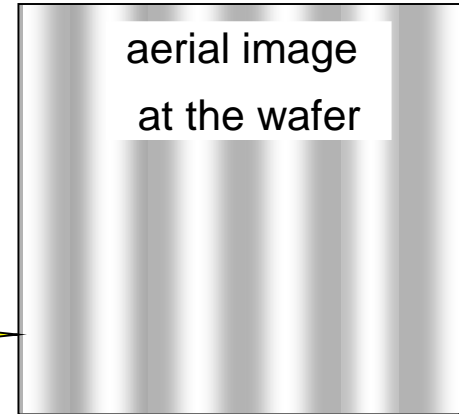
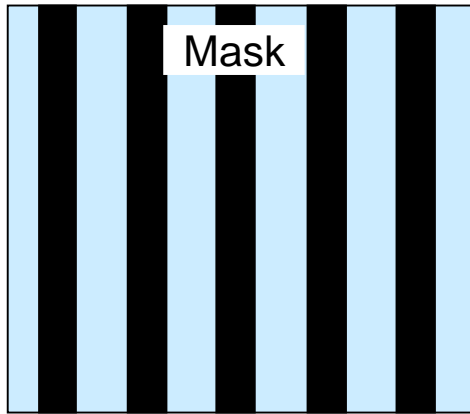


$$\sin \theta_{max} = 2NA = \lambda/p_{min}$$

$$R = \frac{p_{min}}{2} = 0.25 \frac{\lambda}{NA}$$



Chemist's view of how things really work

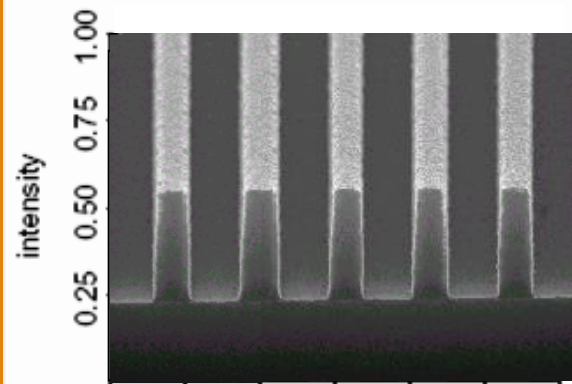


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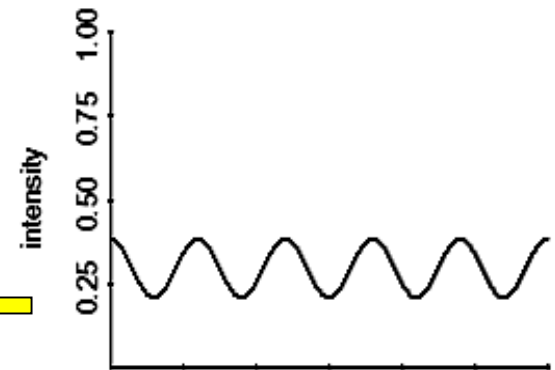


Amazing Chemistry!!

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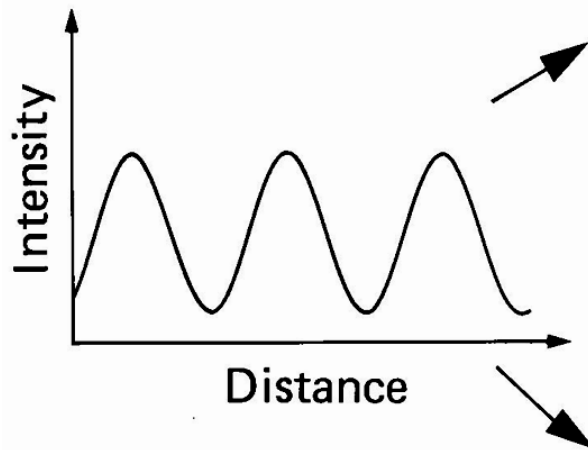
resist image



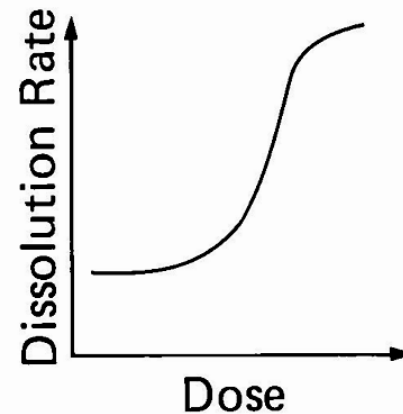
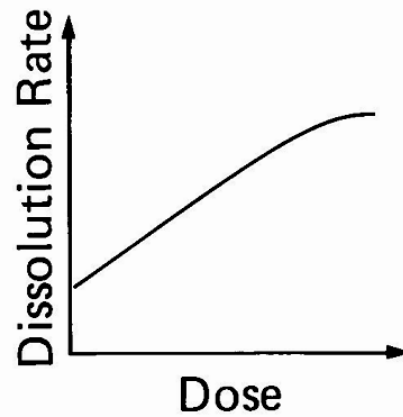
aerial image



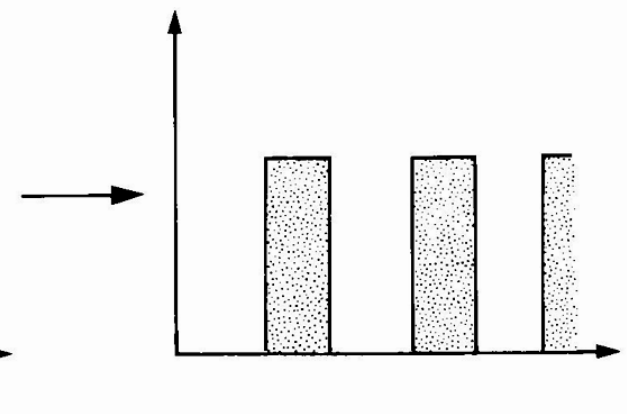
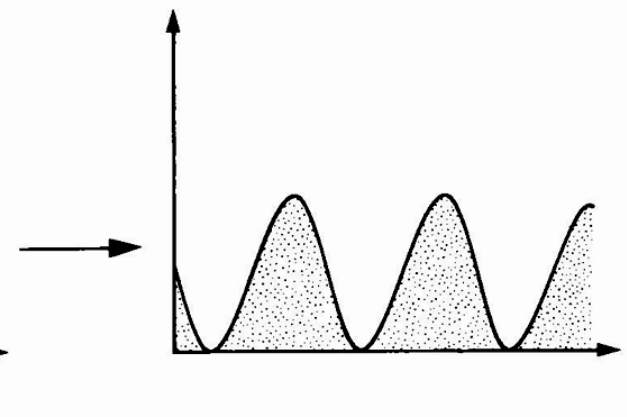
Non-linear dissolution rate response



Projected Intensity
Function



Resist Response
Function



Resist Profile

