PAUL SCHERRER INSTITUT

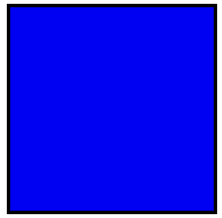
PSI

Rasmus Ischebeck

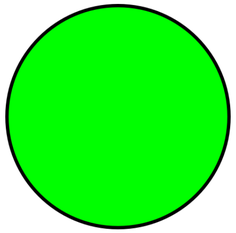
Interaction of X-Rays with Matter

Joint Universities Accelerator School

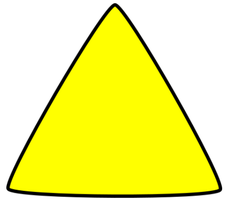
Quiz: Which Components Primarily Determine the Interaction of X-Rays with Matter?



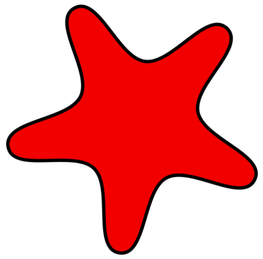
Protons



Electrons

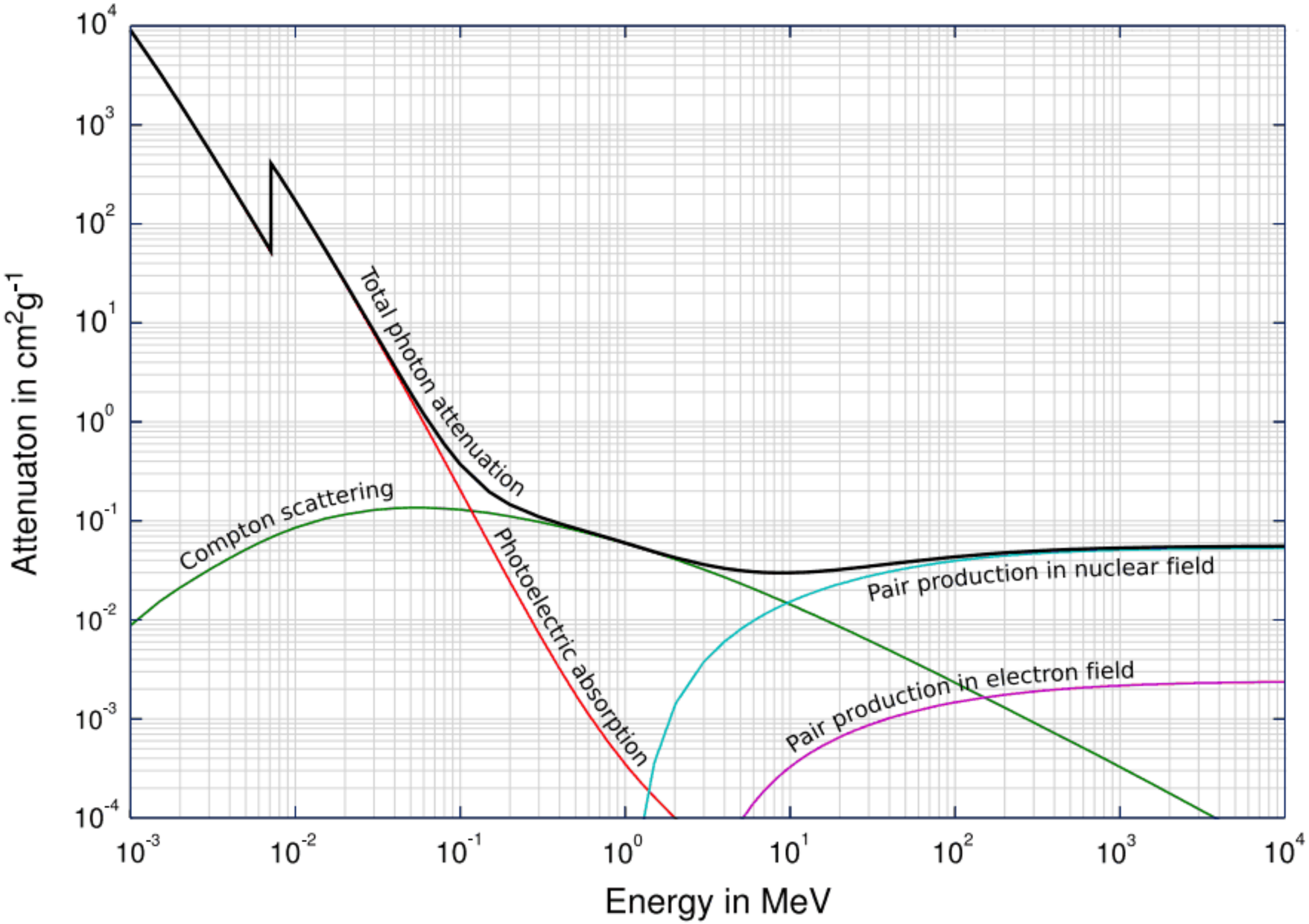


Neutrons

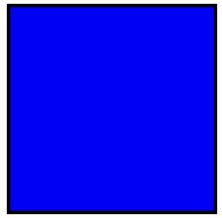


Klingons

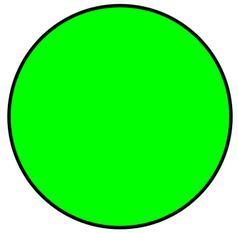
What Processes Contribute to X-Ray Cross Section?



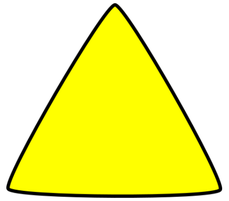
Quiz: A photon undergoes an elastic collision. What does this mean? More than one answer possible.



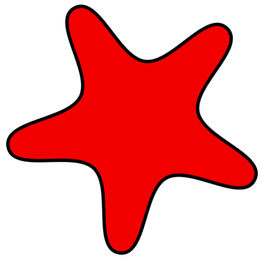
The photon has the same energy before and after collision



The photon has the same momentum vector before and after collision

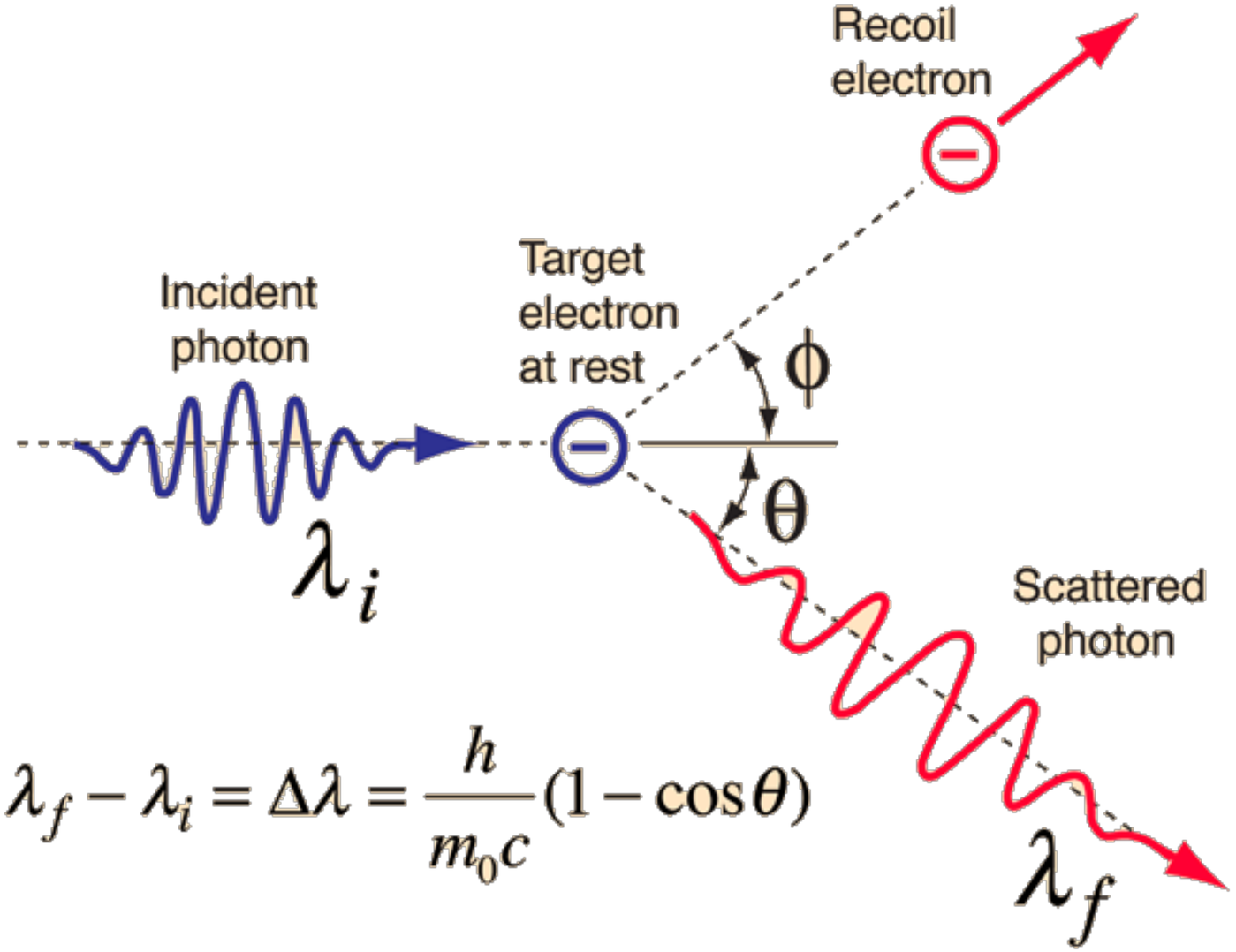


The photon has the same wavelength before and after collision



Complete transfer of the photon's energy to the collision partner

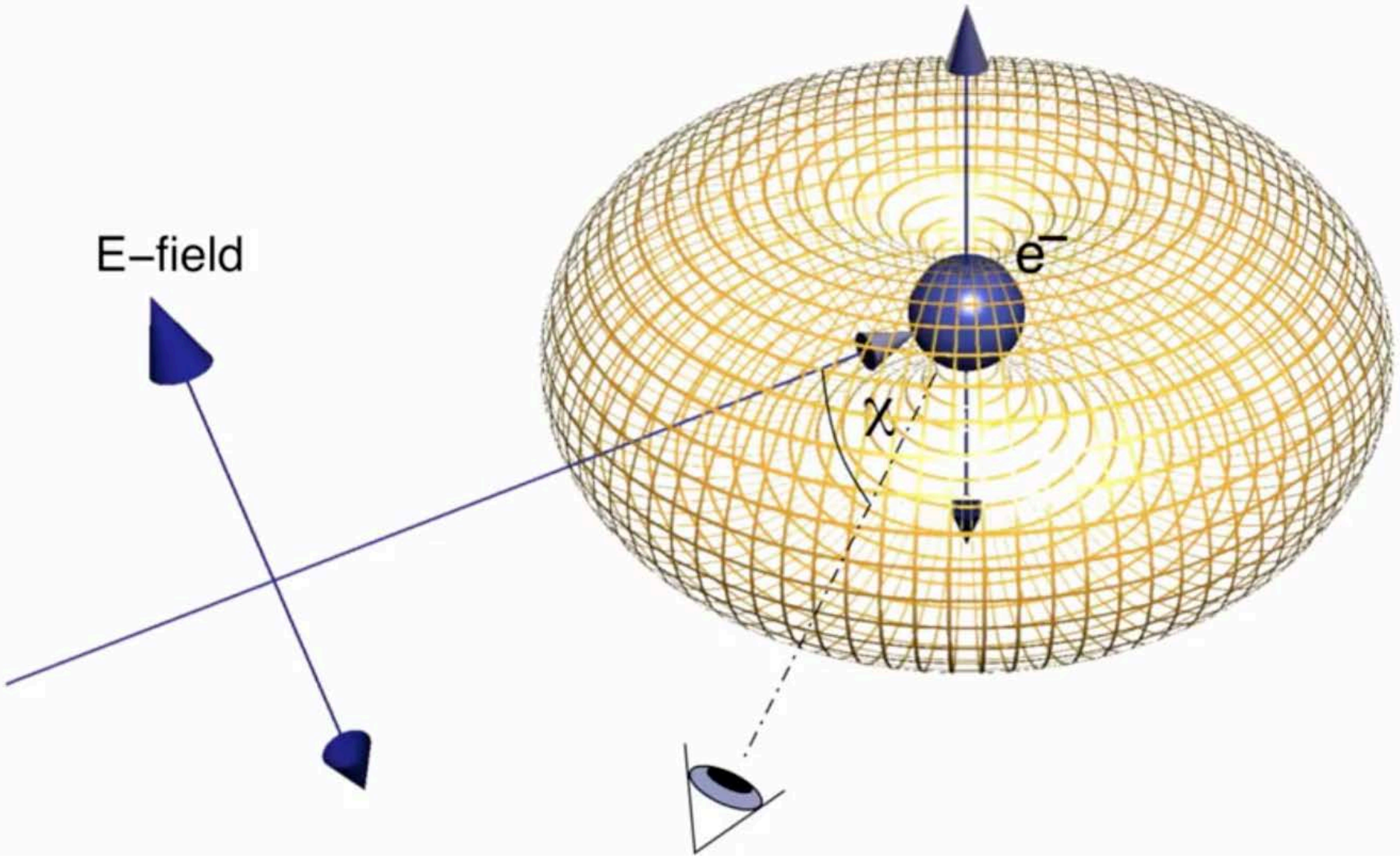
Compton Scattering



$$\lambda_f - \lambda_i = \Delta\lambda = \frac{h}{m_0 c}(1 - \cos\theta)$$

http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/compton.html

Thomson Scattering: Elastic Scattering on Free Electrons

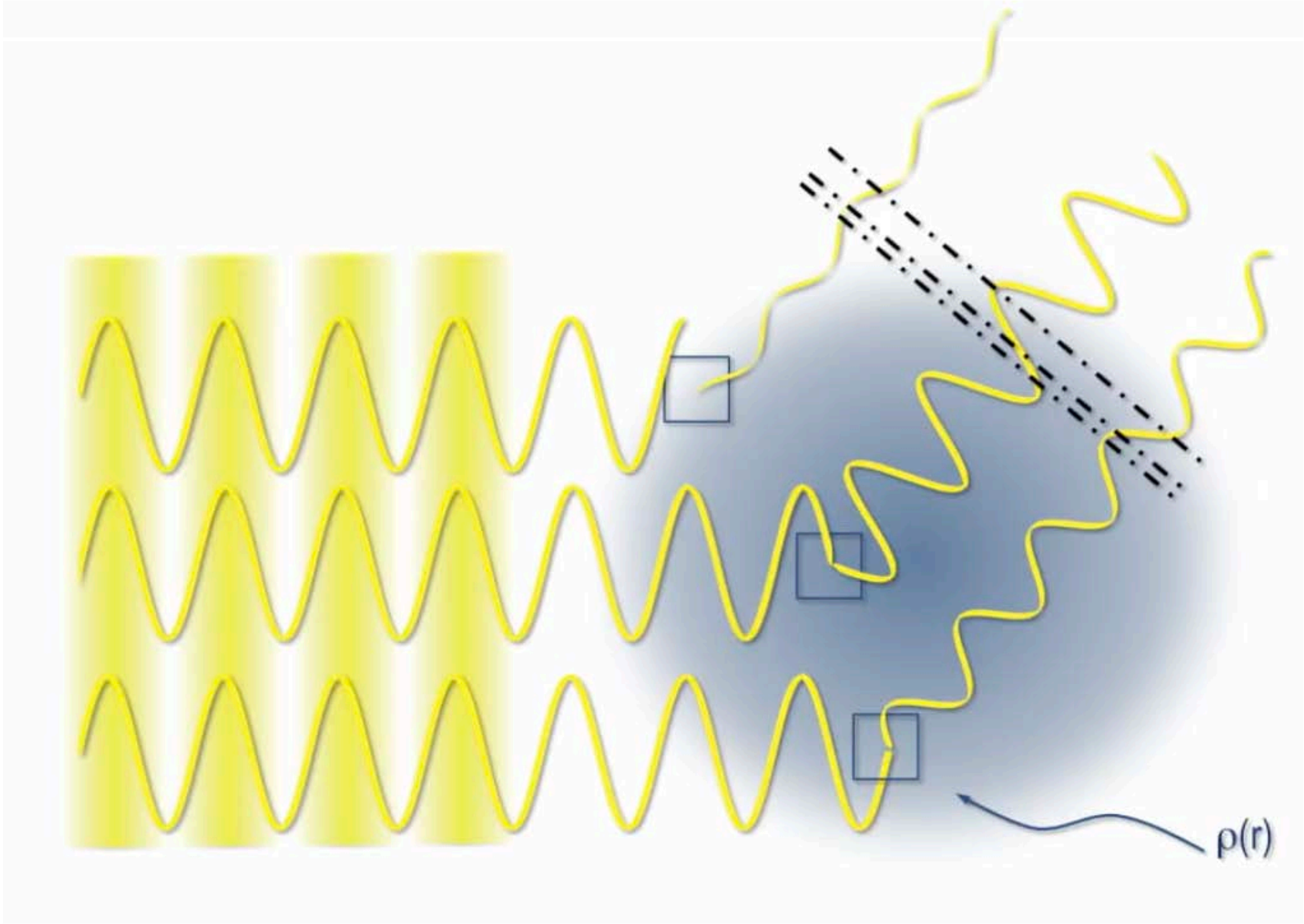


$$I = I_0 \cos^2\chi$$

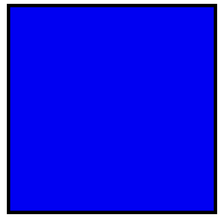
Electrons Bound to an Atom

Wikimedia Commons

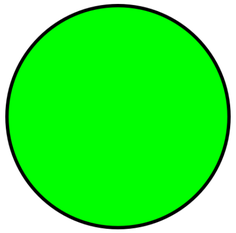
Absorption by Higher Energy Photons



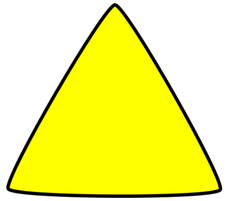
Quiz: In Which Element are the Core Electrons Most Strongly Bound to the Atom?



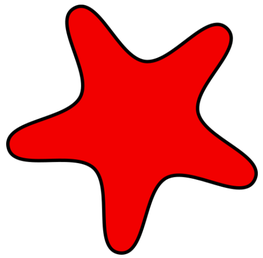
Hydrogen



Silicon

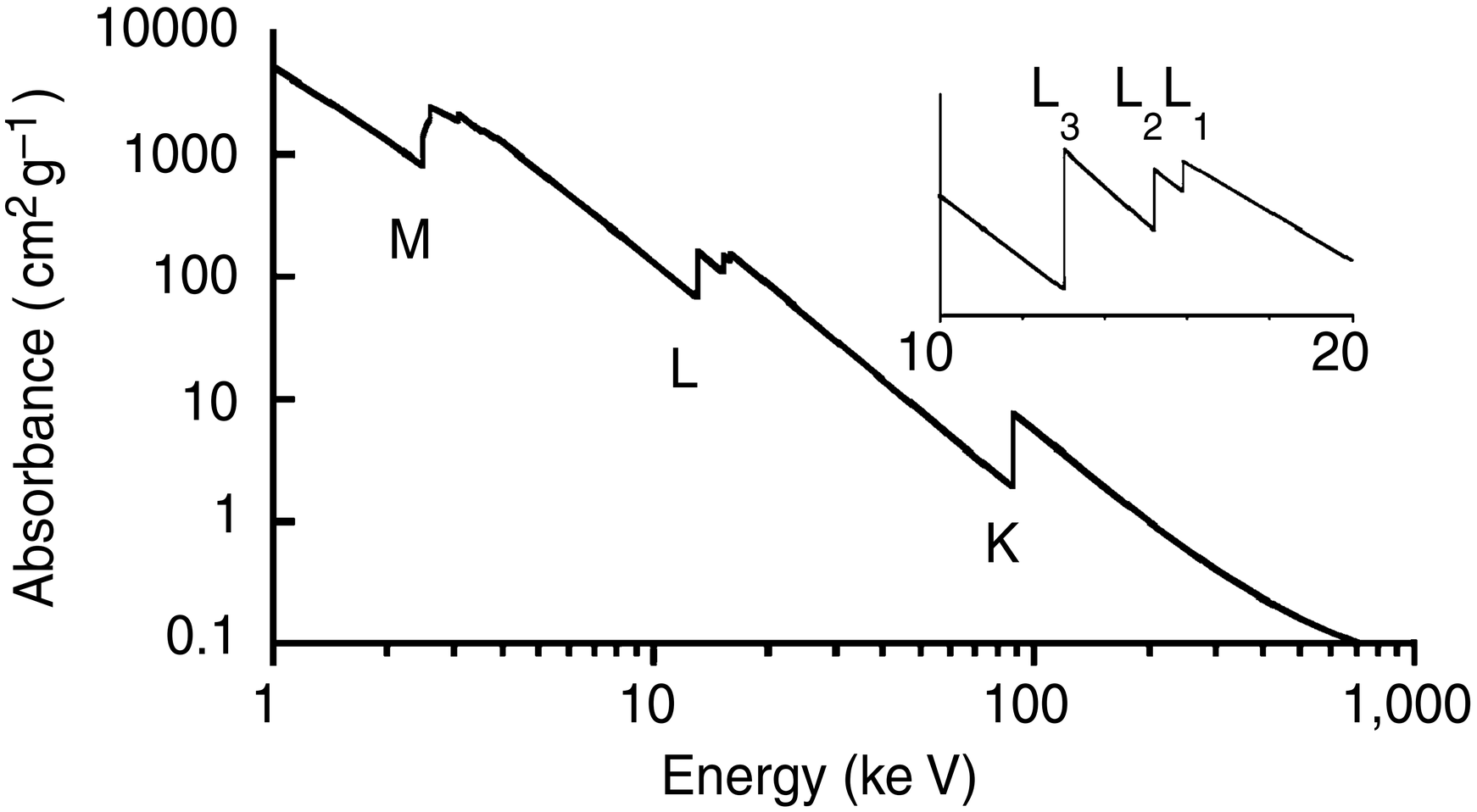


Iron

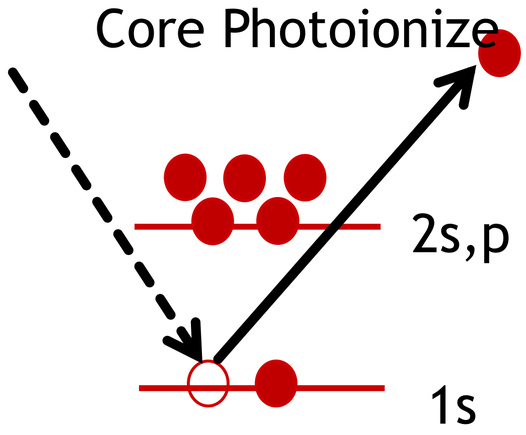


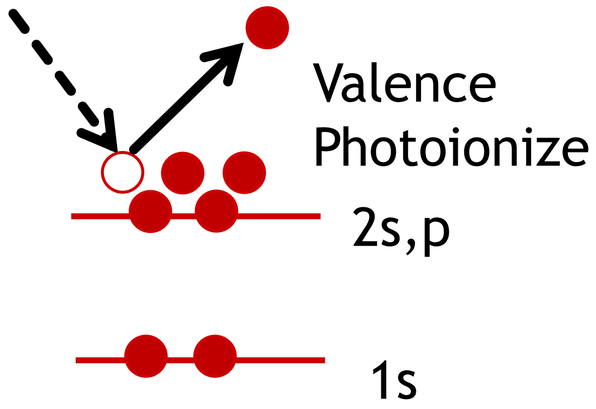
Gold

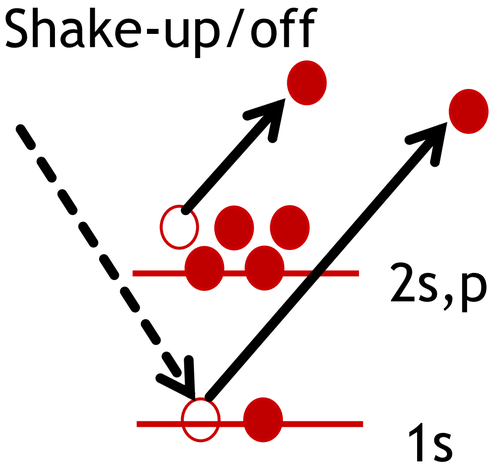
X-Ray Absorption Spectrum of Lead

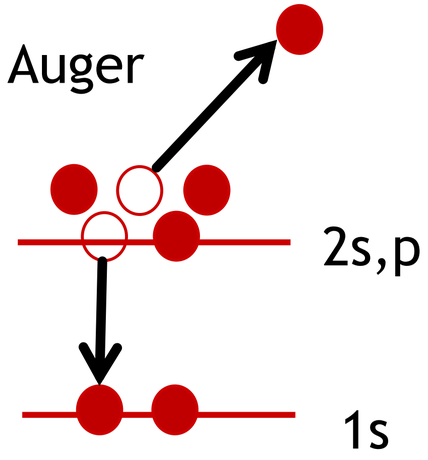


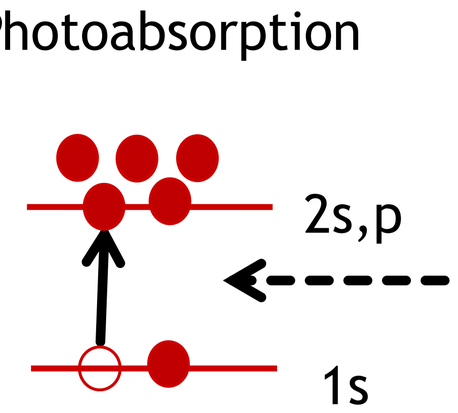
Processes

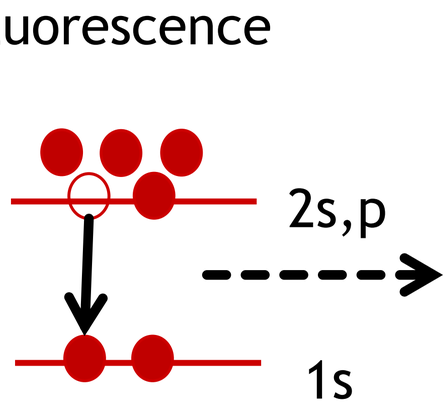

Core Photoionize
2s,p
1s


Valence
Photoionize
2s,p
1s

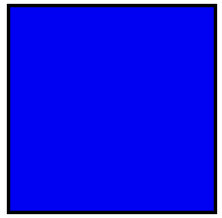

Shake-up/off
2s,p
1s


Auger
2s,p
1s

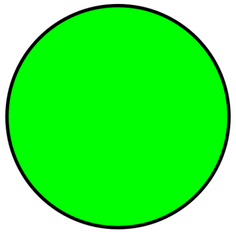

Photoabsorption
2s,p
1s


Fluorescence
2s,p
1s

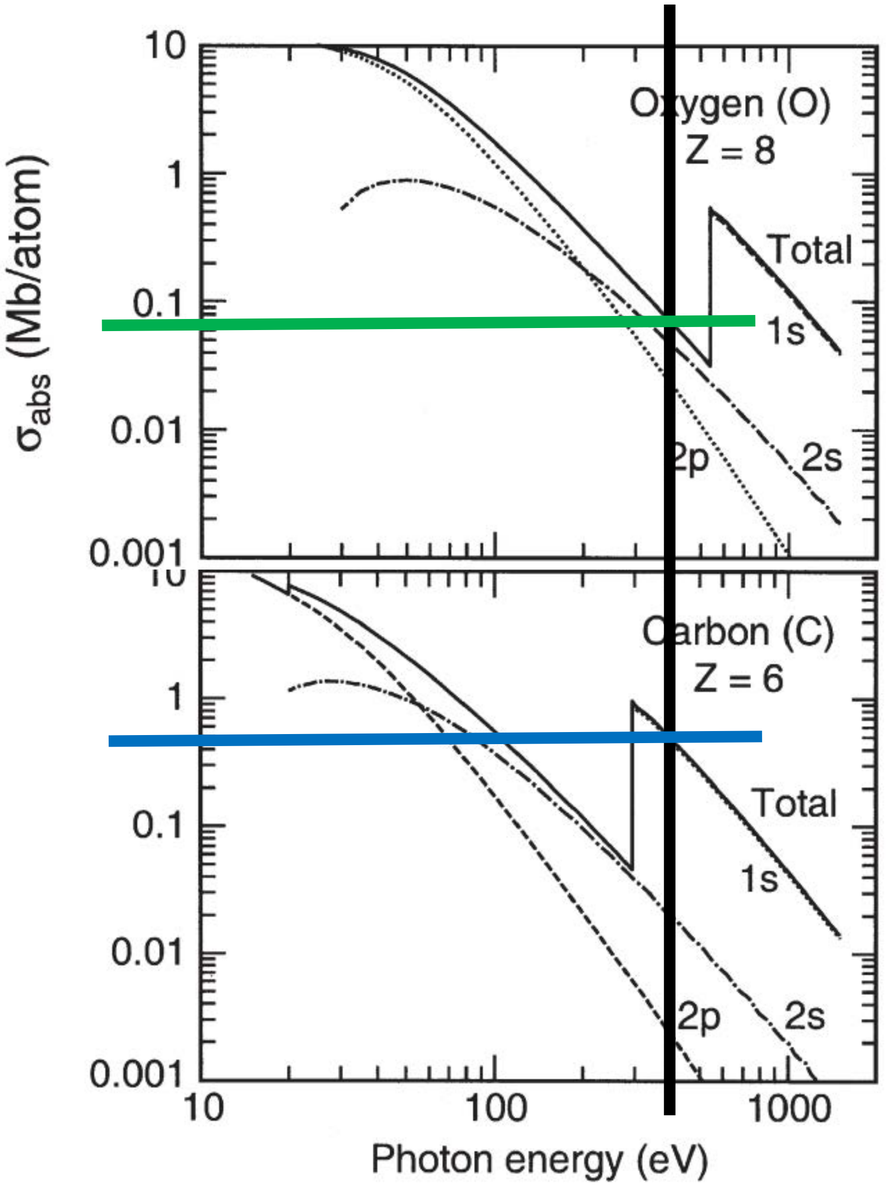
Which Atoms Absorb 0.4 keV X-Rays More Strongly?



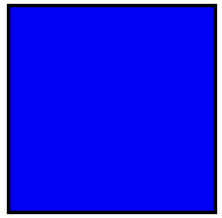
Carbon (Z=6)



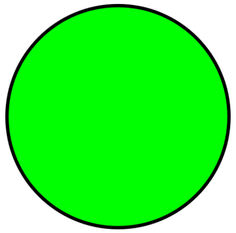
Oxygen (Z=8)



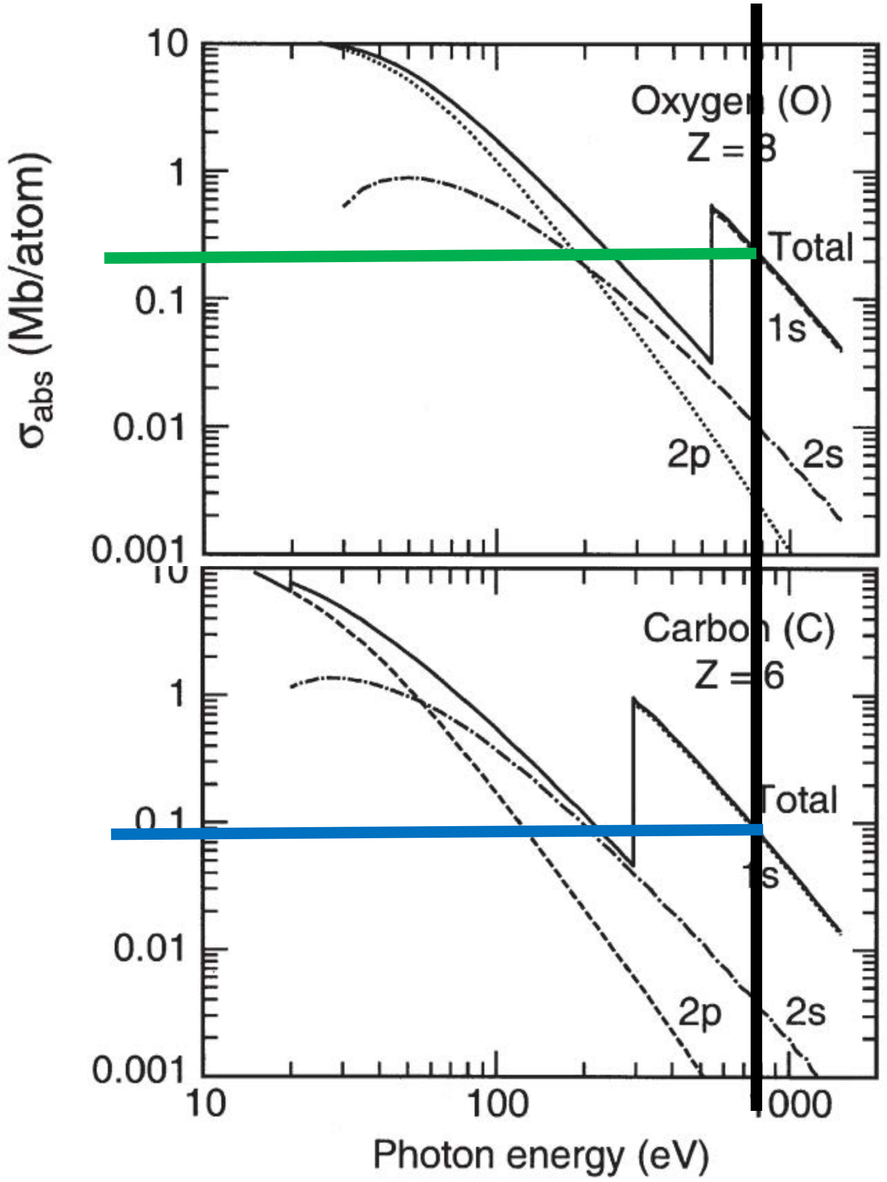
Which Atoms Absorb 0.8 keV X-Rays More Strongly?



Carbon (Z=6)



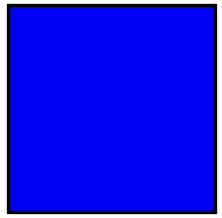
Oxygen (Z=8)



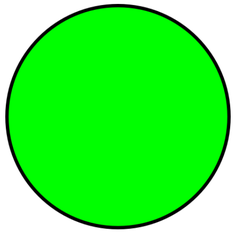
Crystals

Wikimedia Commons

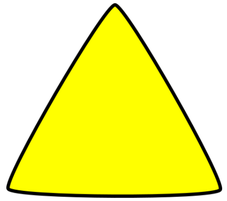
Which of These are Crystals?



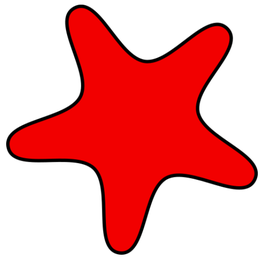
Salt



Silicon wafers for computer chips



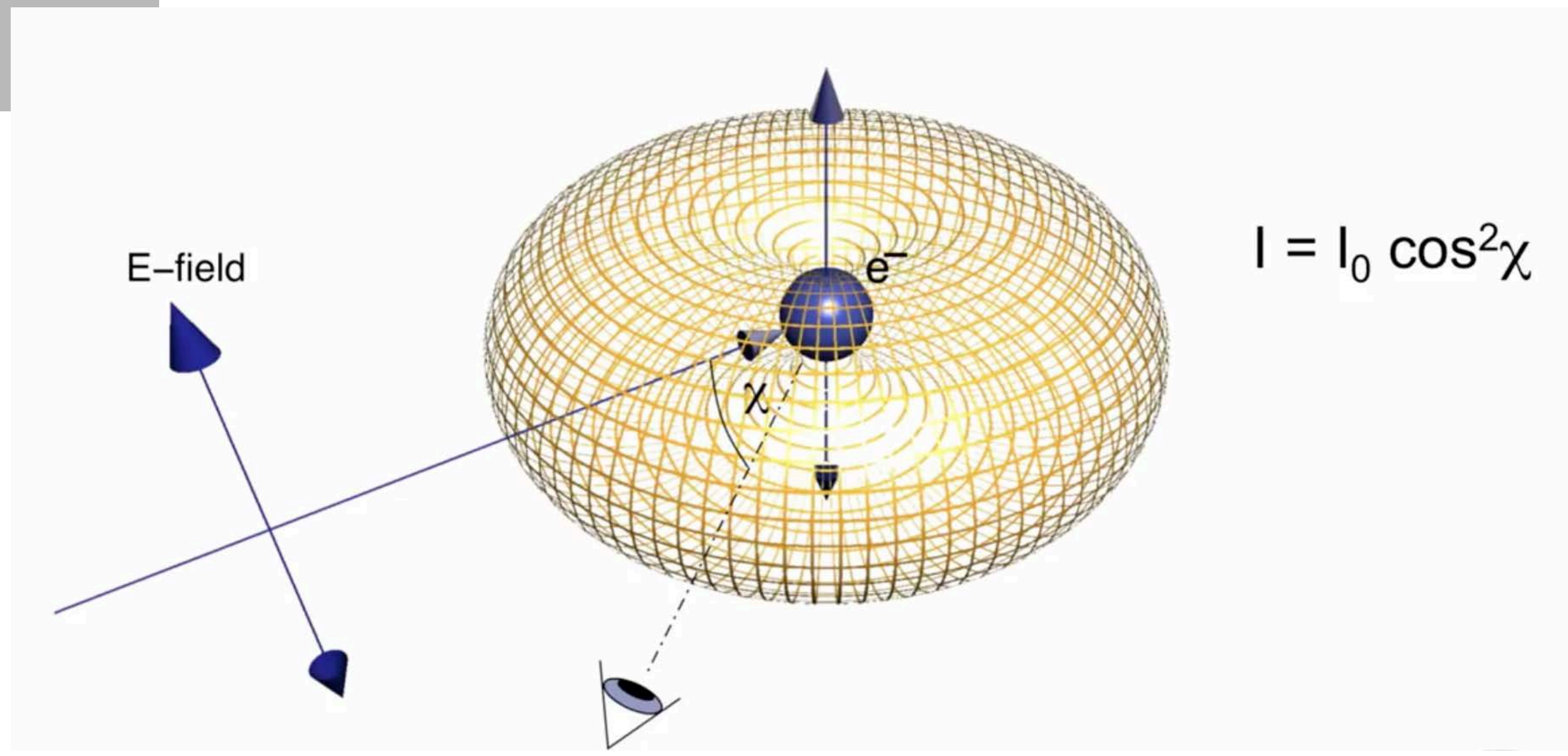
Diamonds

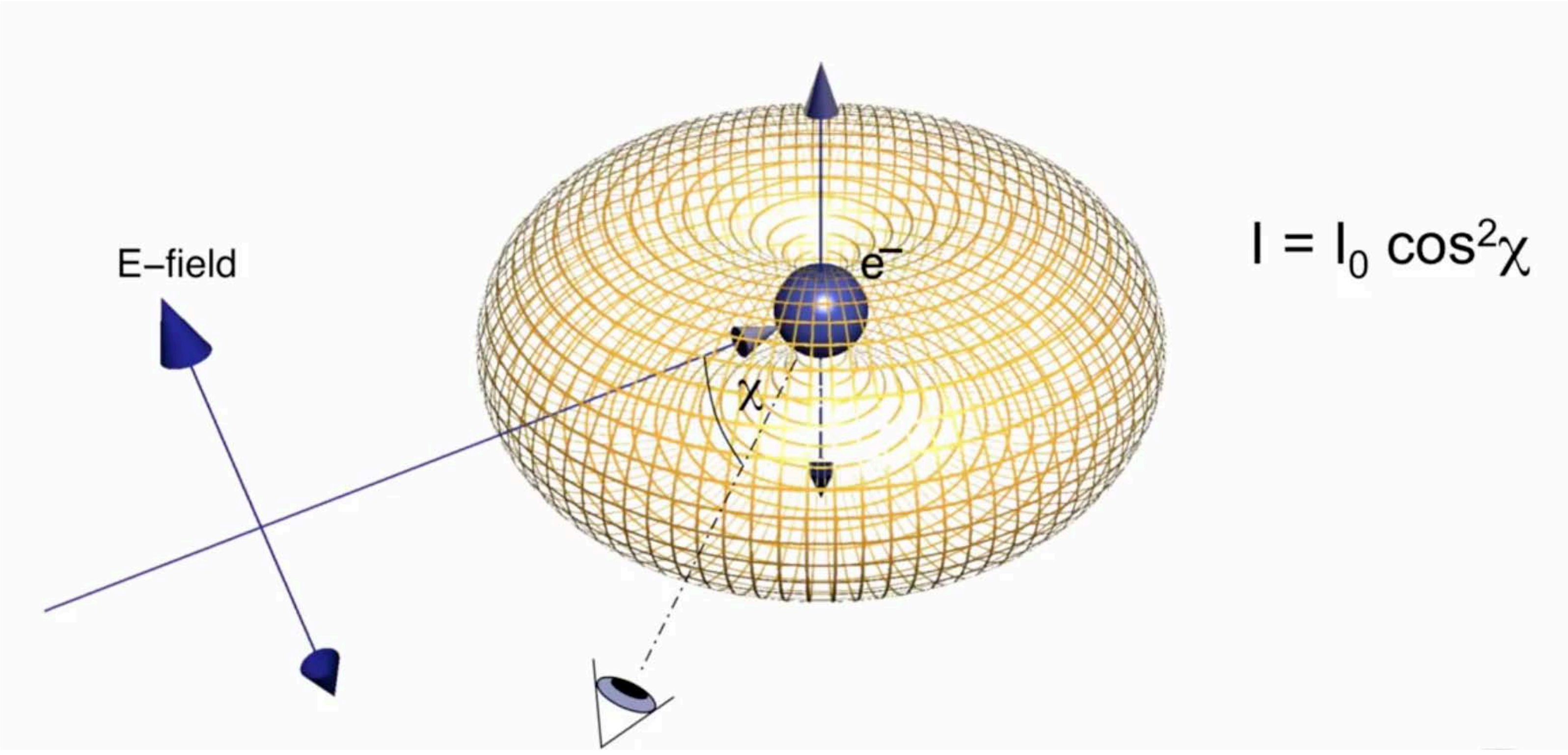


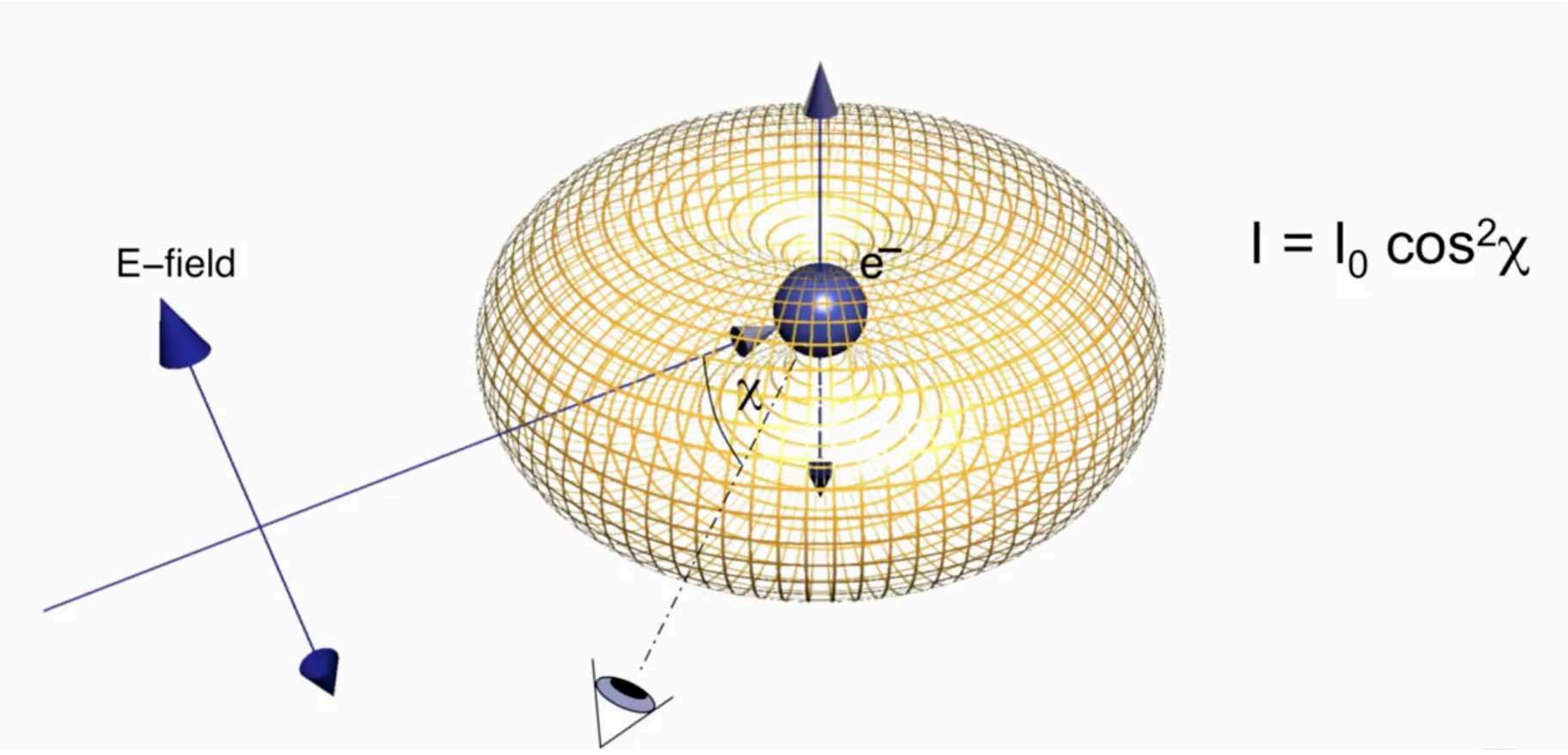
All of the above

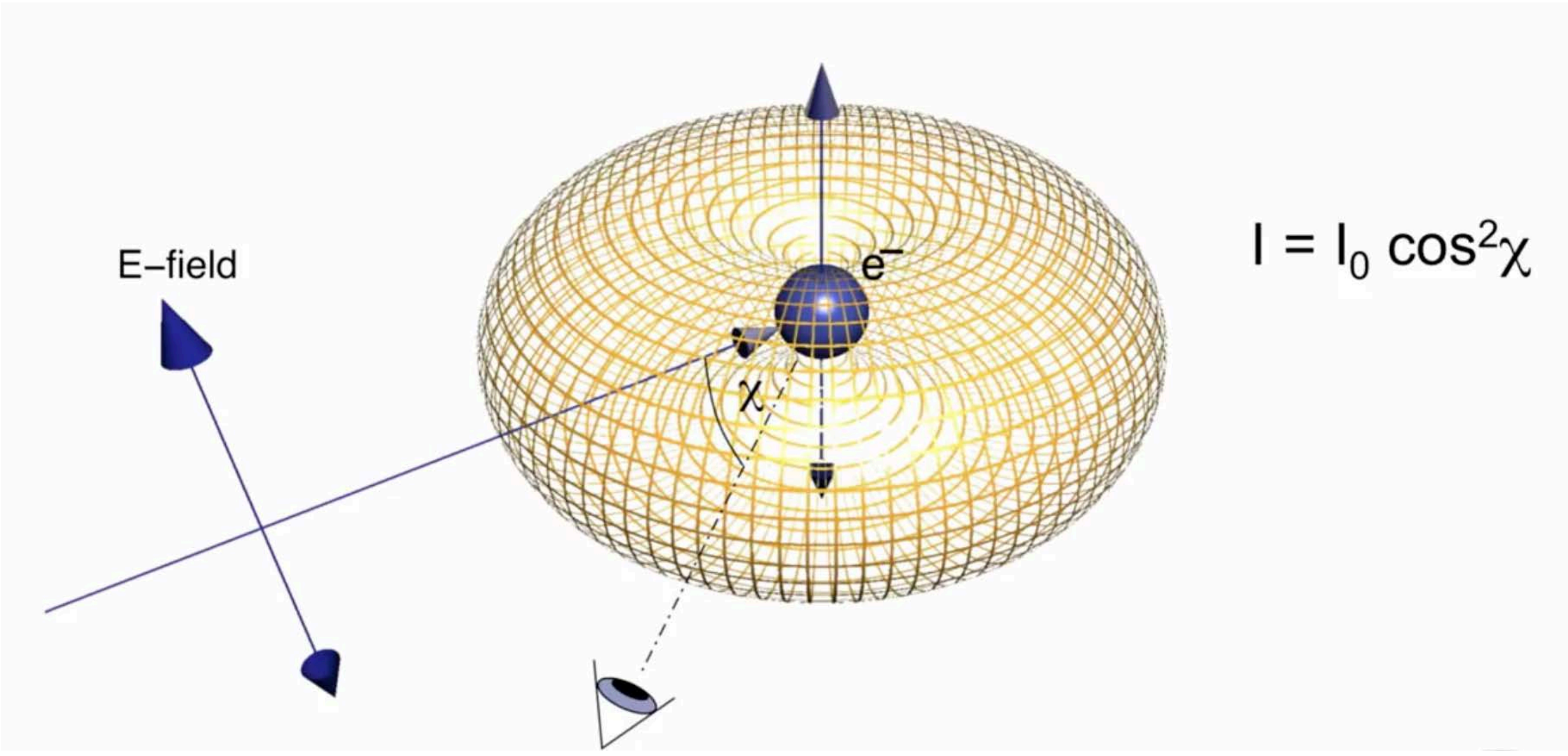
What are Not Crystals?

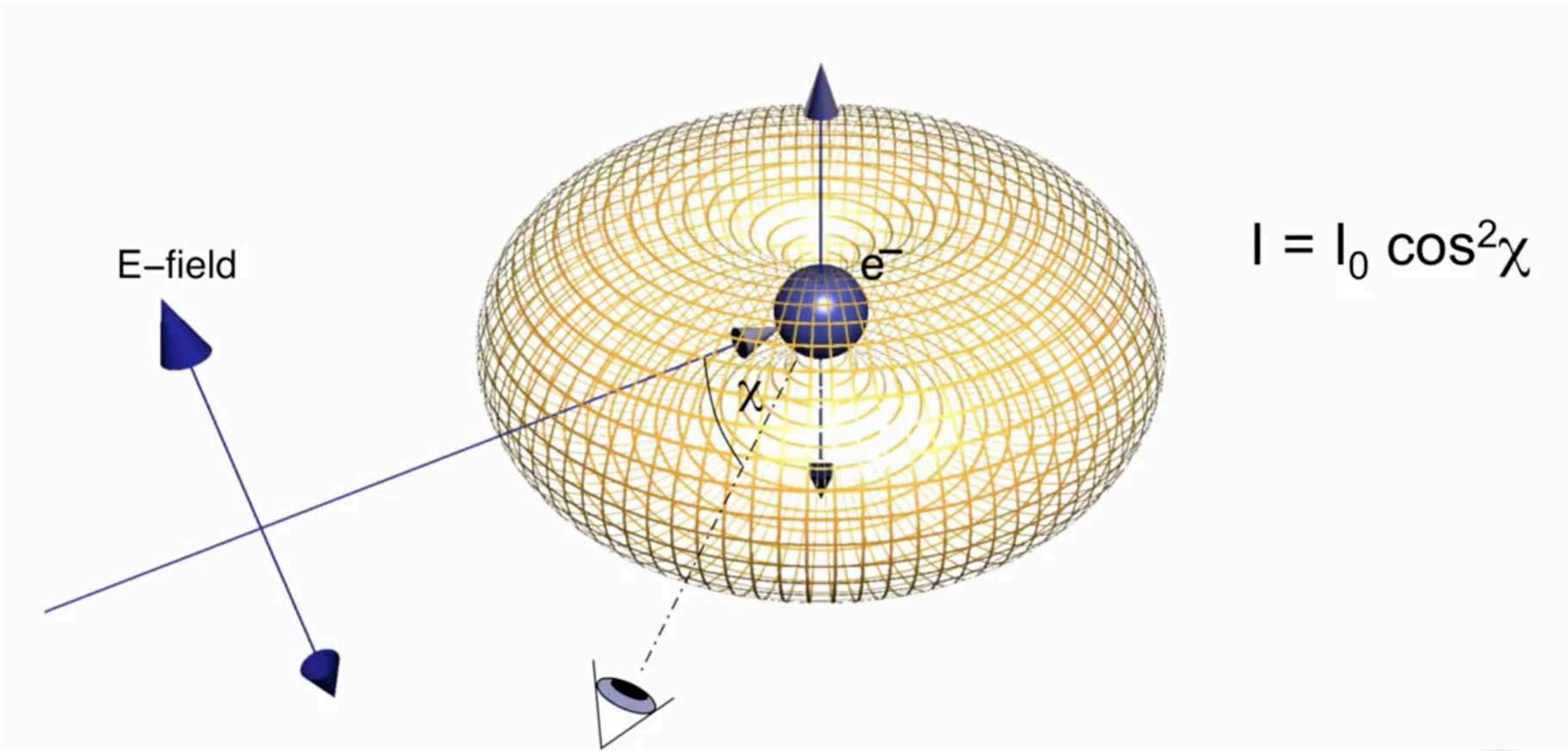
Diffraction

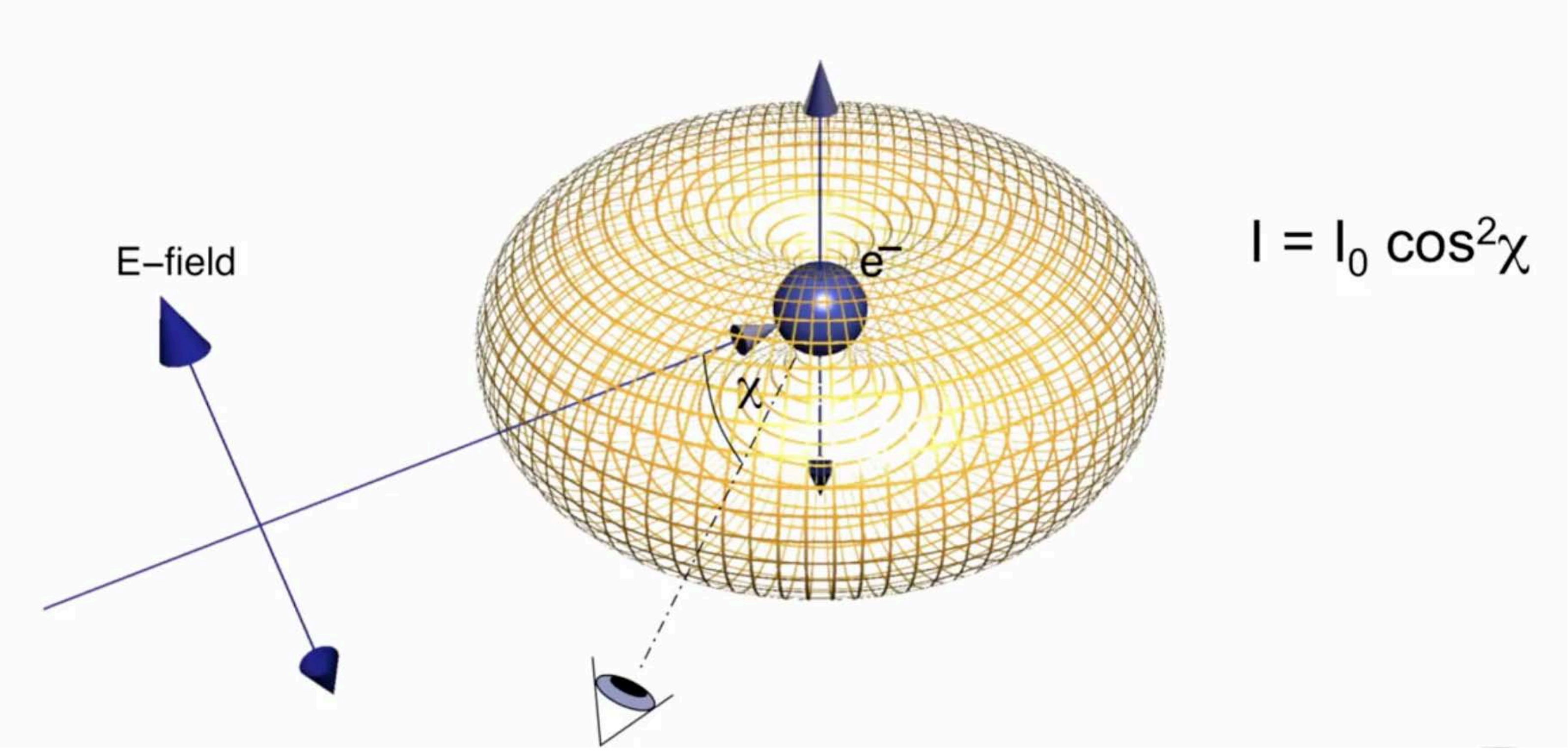




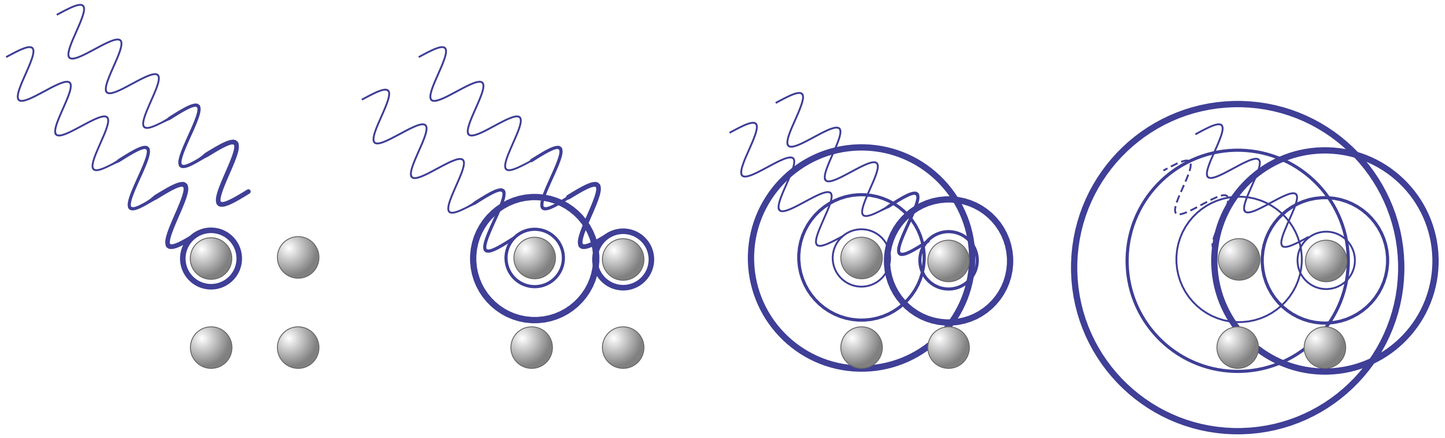


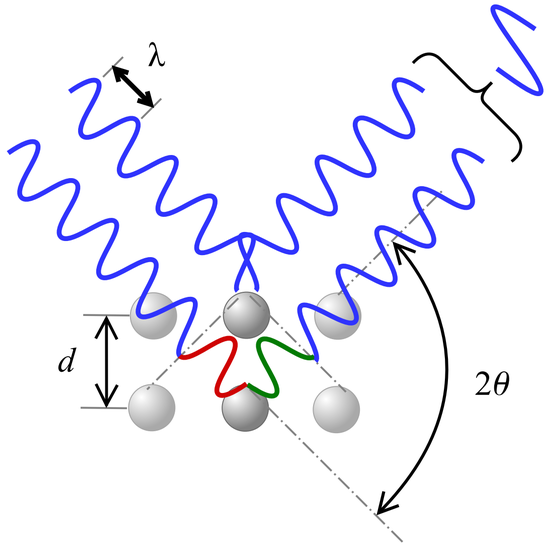


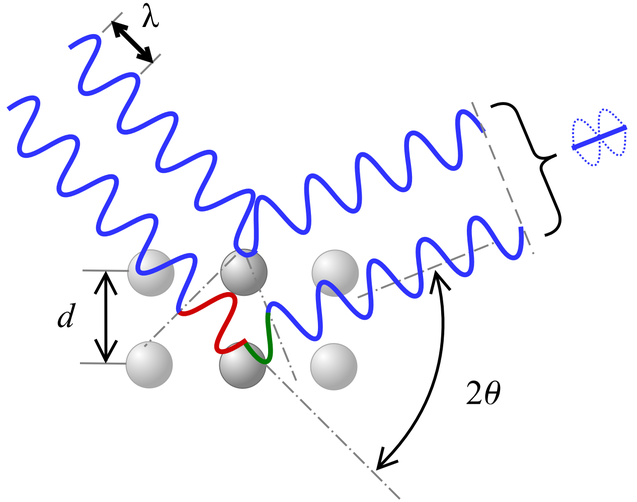




Diffraction





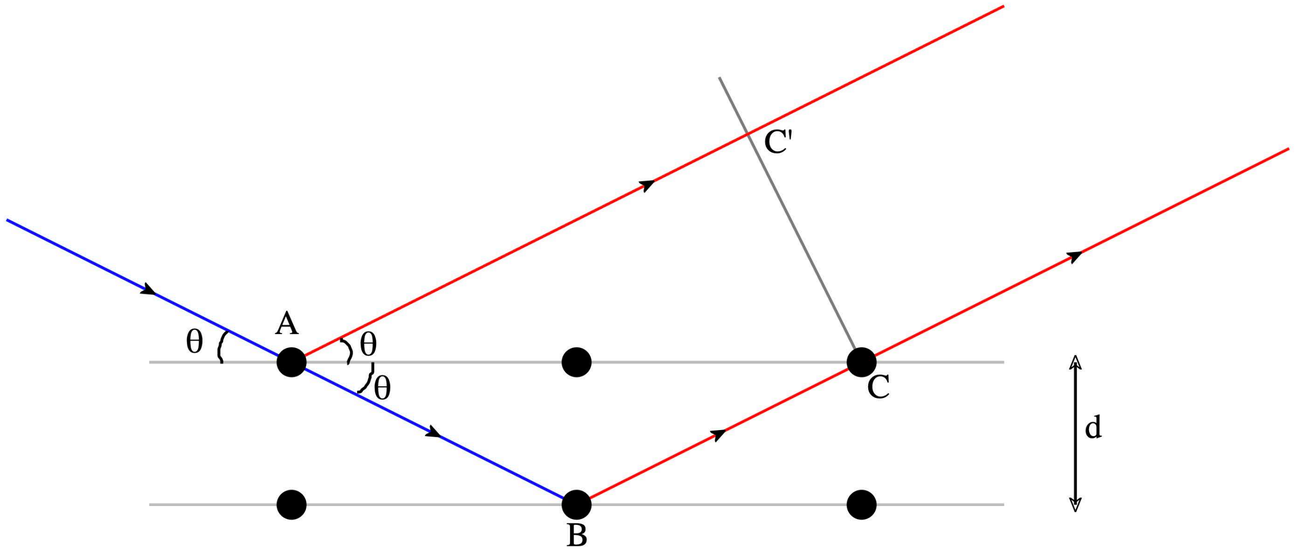


Wikimedia Commons

Bragg's Law

$$(AB + BC) - (AC') = n\lambda\,,$$

where the same definition of n and λ apply as above



Wikimedia Commons

Therefore,

$$AB = BC = \frac{d}{\sin\theta} \text{ and } AC = \frac{2d}{\tan\theta}\,,$$

from which it follows that

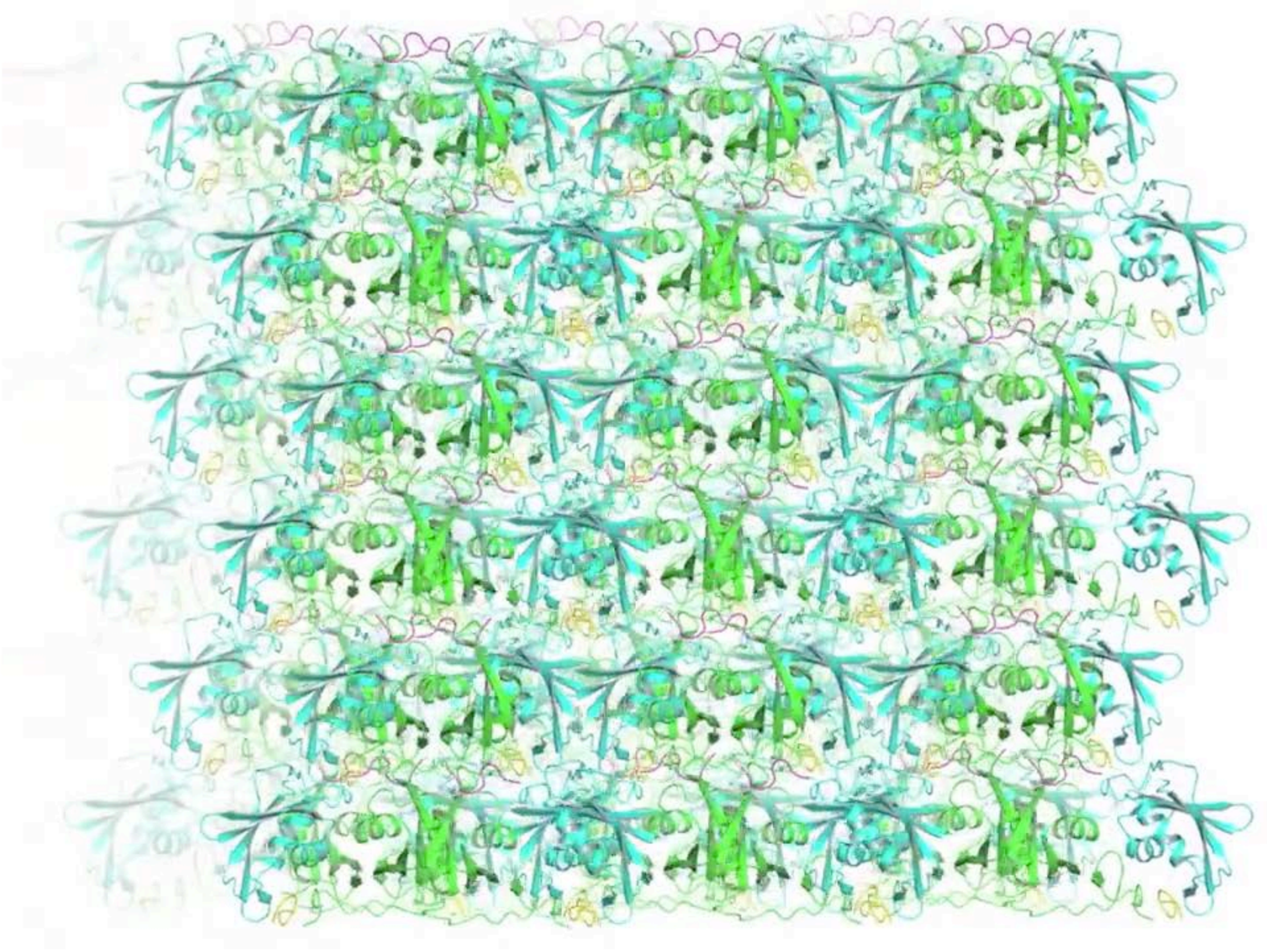
$$AC' = AC \cdot \cos\theta = \frac{2d}{\tan\theta}\cos\theta = \left(\frac{2d}{\sin\theta}\cos\theta\right)\cos\theta = \frac{2d}{\sin\theta}\cos^2\theta$$

Putting everything together,

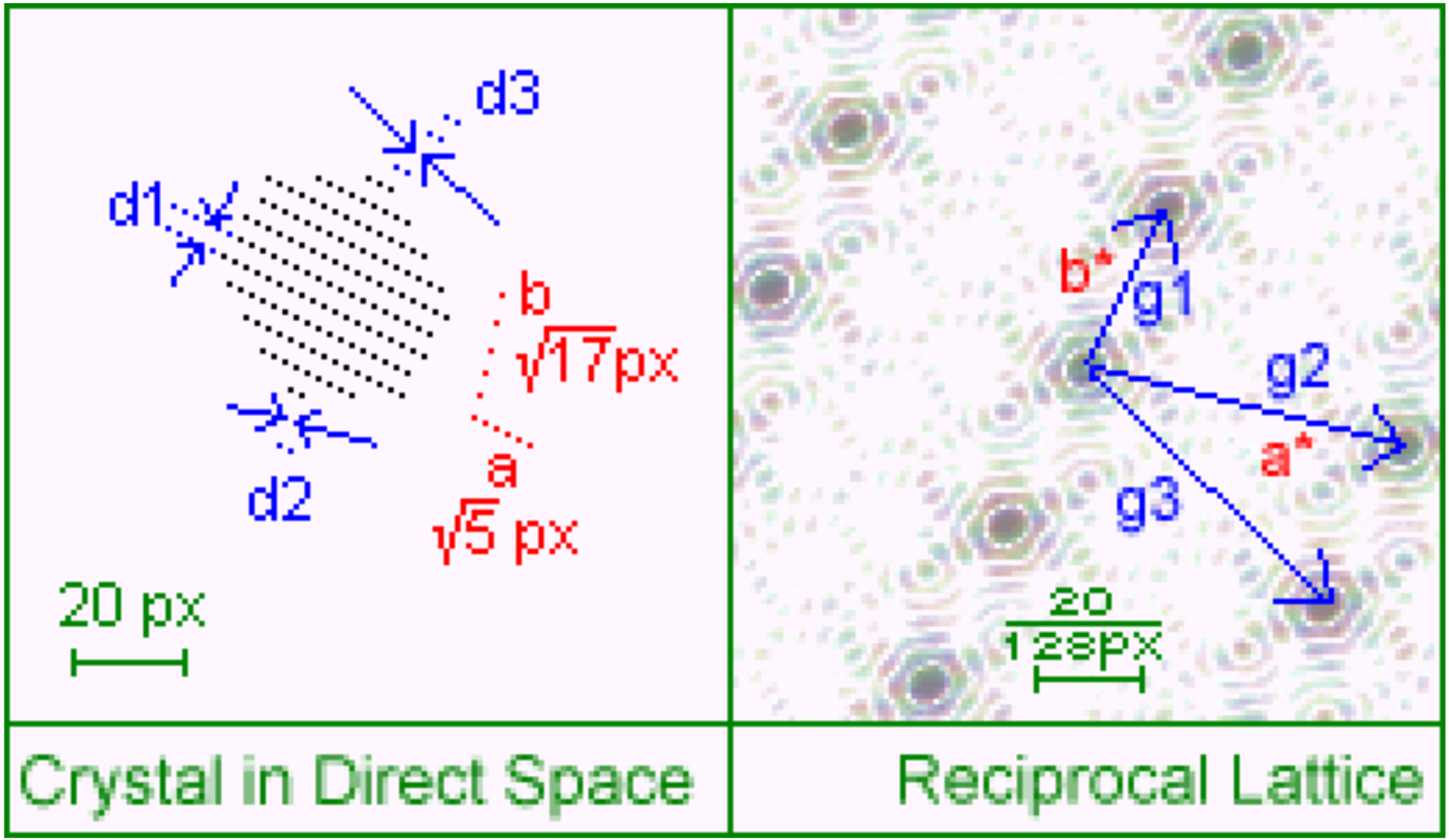
$$n\lambda = \frac{2d}{\sin\theta} - \frac{2d}{\tan\theta}\cos\theta = \frac{2d}{\sin\theta}\left(1 - \cos^2\theta\right) = \frac{2d}{\sin\theta}\sin^2\theta$$

which simplifies to $n\lambda = 2d\sin\theta$, which is Bragg's law.

Diffraction on Molecular Crystals



Fourier Transform



Wikimedia Commons

Questions?