

More about light, Properties  
of waves, Refraction, Lenses

- Slides and HWs posted at:

- [http://spot.colorado.edu/~jokr7175/teaching\\_docs.html](http://spot.colorado.edu/~jokr7175/teaching_docs.html)

- Matlab tutorials:

- <https://matlabacademy.mathworks.com/>

- [Matlab intro PDF](#)

- Other note – I will not be available this Thur (8/31) from 10-11. Let me know if you want to meet another time.

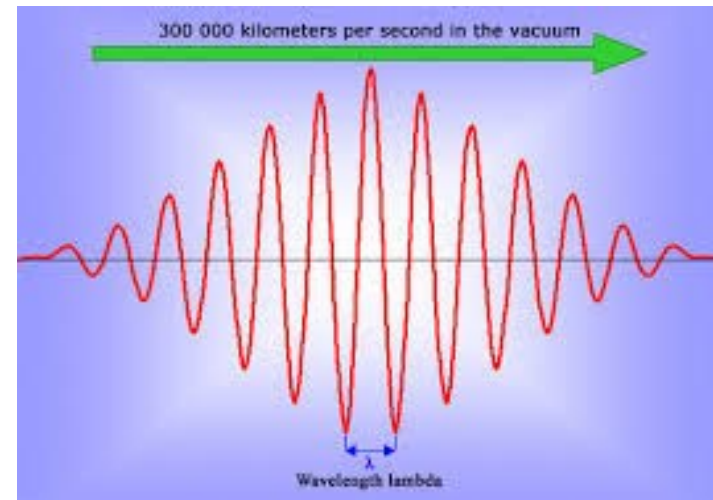
- Last class – Fundamentals of light and color
  - Light acts as a particle
  - Light acts as a wave
  - Light is a photon
- This class
  - Detection of light
  - Refraction, and how it changes light waves
  - Optical elements taking advantage of refraction

# Light has both particle and wavelike features

- The double slit proved light is wavelike, but intensity proves it's lumpy
- Einstein proposed that light comes in discrete packets of energy
- Each packet energy is set by the frequency, and all packets of the same color have the same energy
- Each of these particles are called *photons*

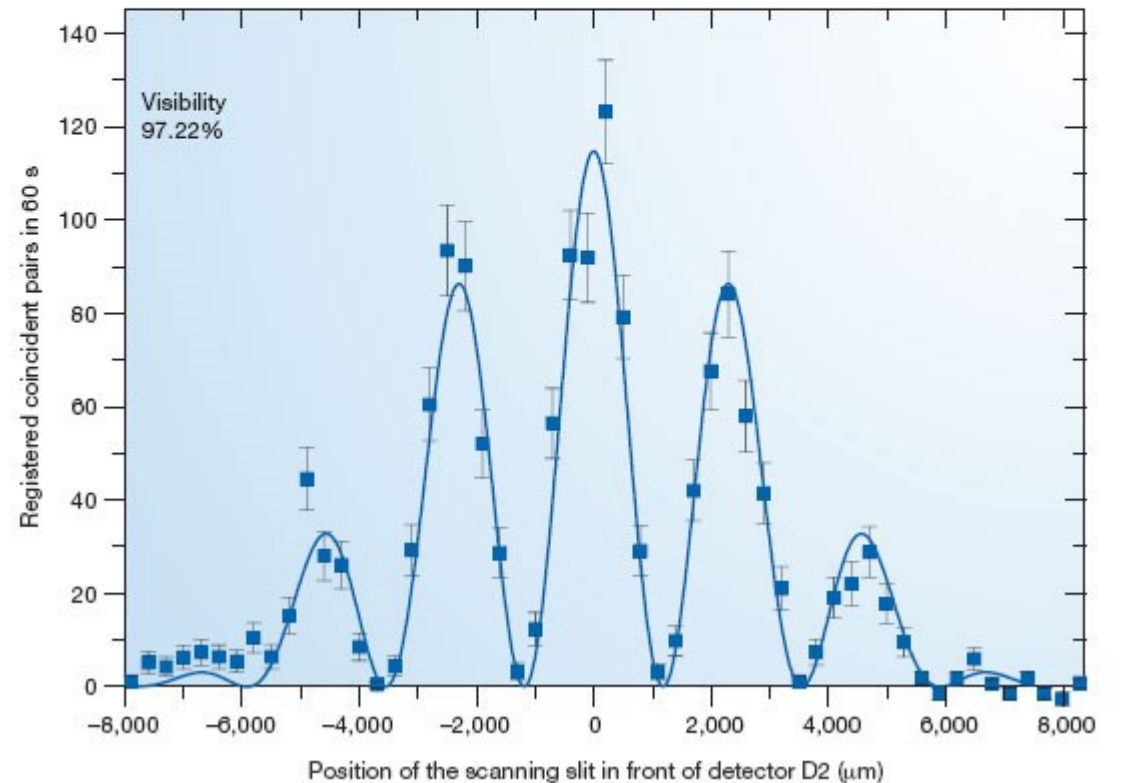
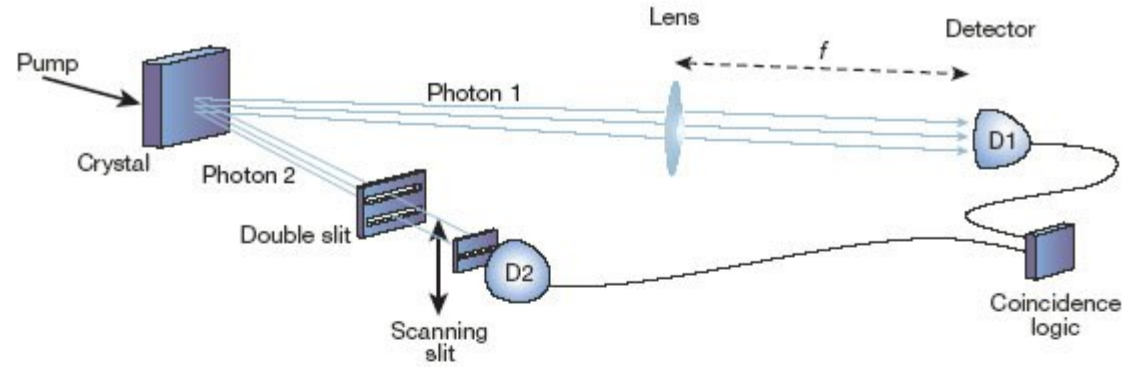
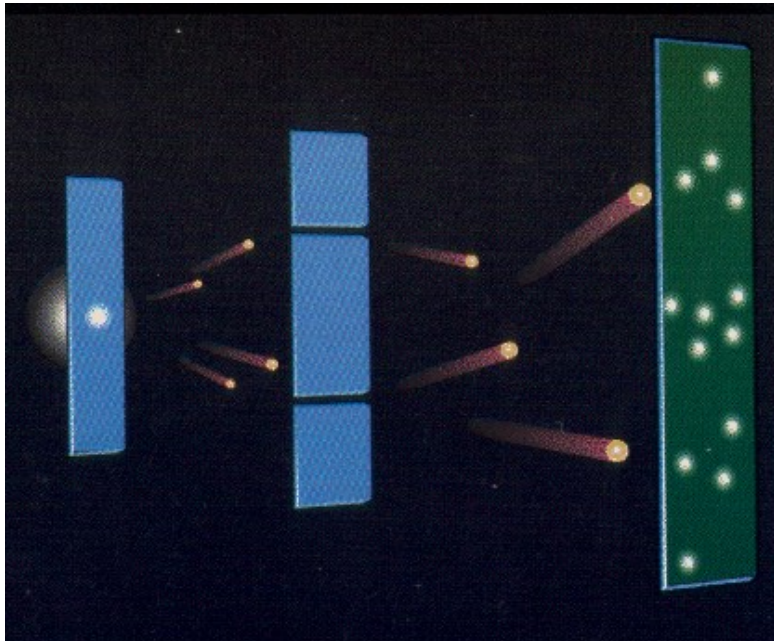
$$E = hf$$
$$= hc/\lambda$$
$$hc = 1240 \text{ eV nm}$$

$h$  = Planck's constant  
=  $6.62 \times 10^{-34} \text{ m}^2\text{kg/s}$

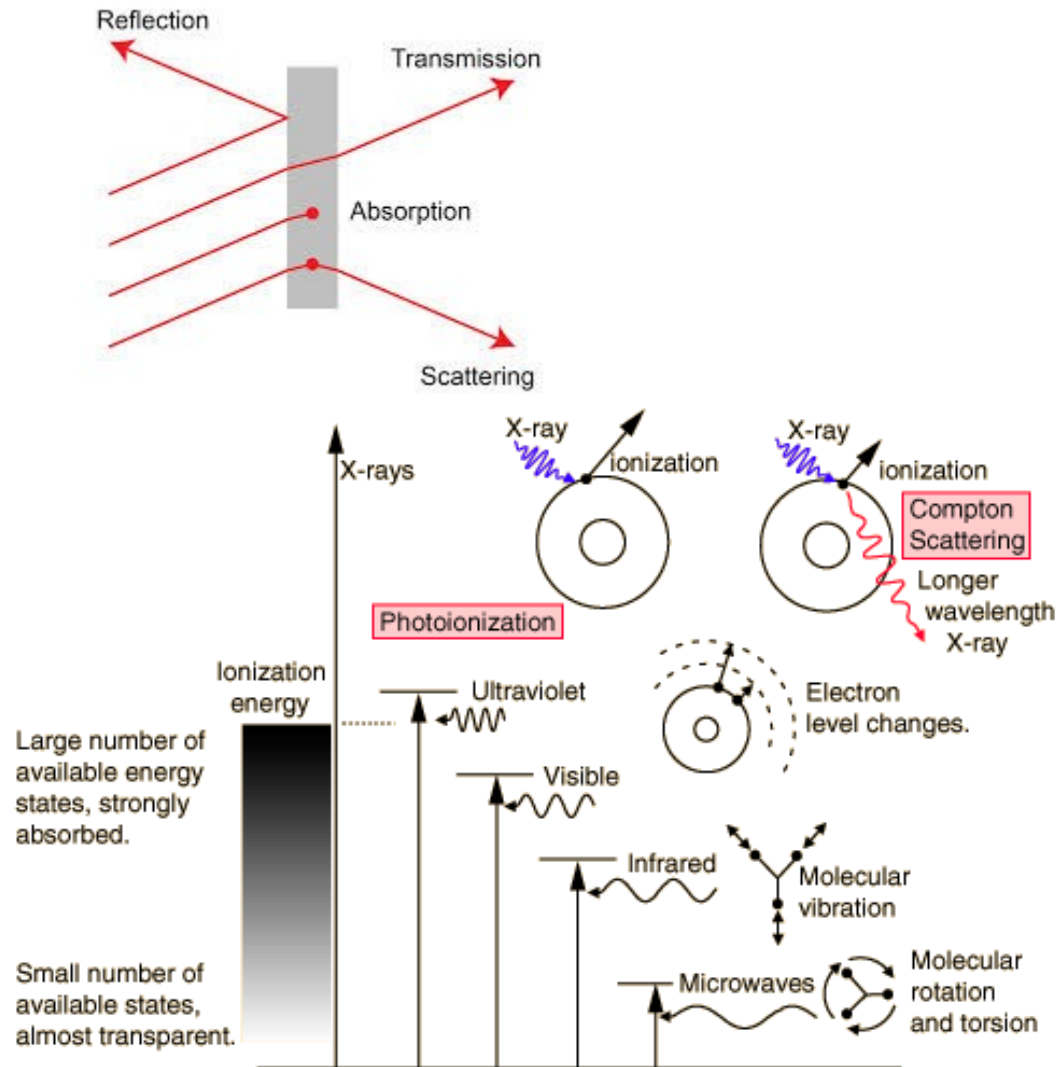


# Quantum weirdness

- A double slit experiment, even with single photons still produces a diffraction pattern
- Monitoring either slit for the passage of the photon will destroy diffraction pattern
- The act of measurement changes photons from waves to particles



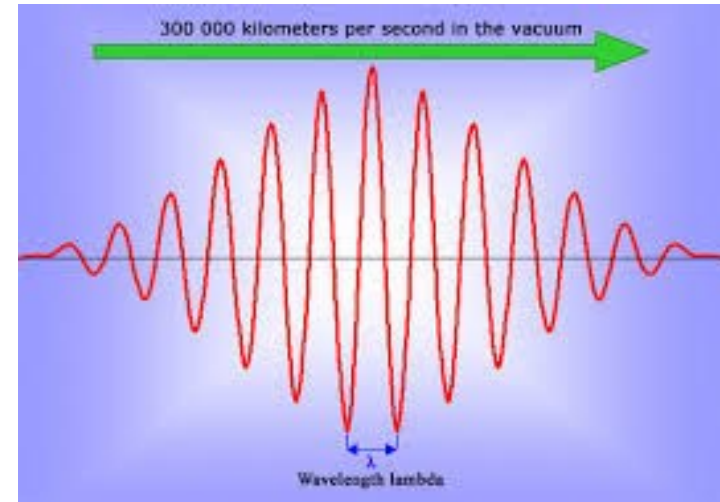
# Light matter interactions– photon -> electron



- Light we deal with (visible) interacts with electrons
- UV-Visible light – electron excitation (orbitals)
- IR light – molecular vibrations
- X-ray light – Ionization, electron is completely removed

# Light matter interactions

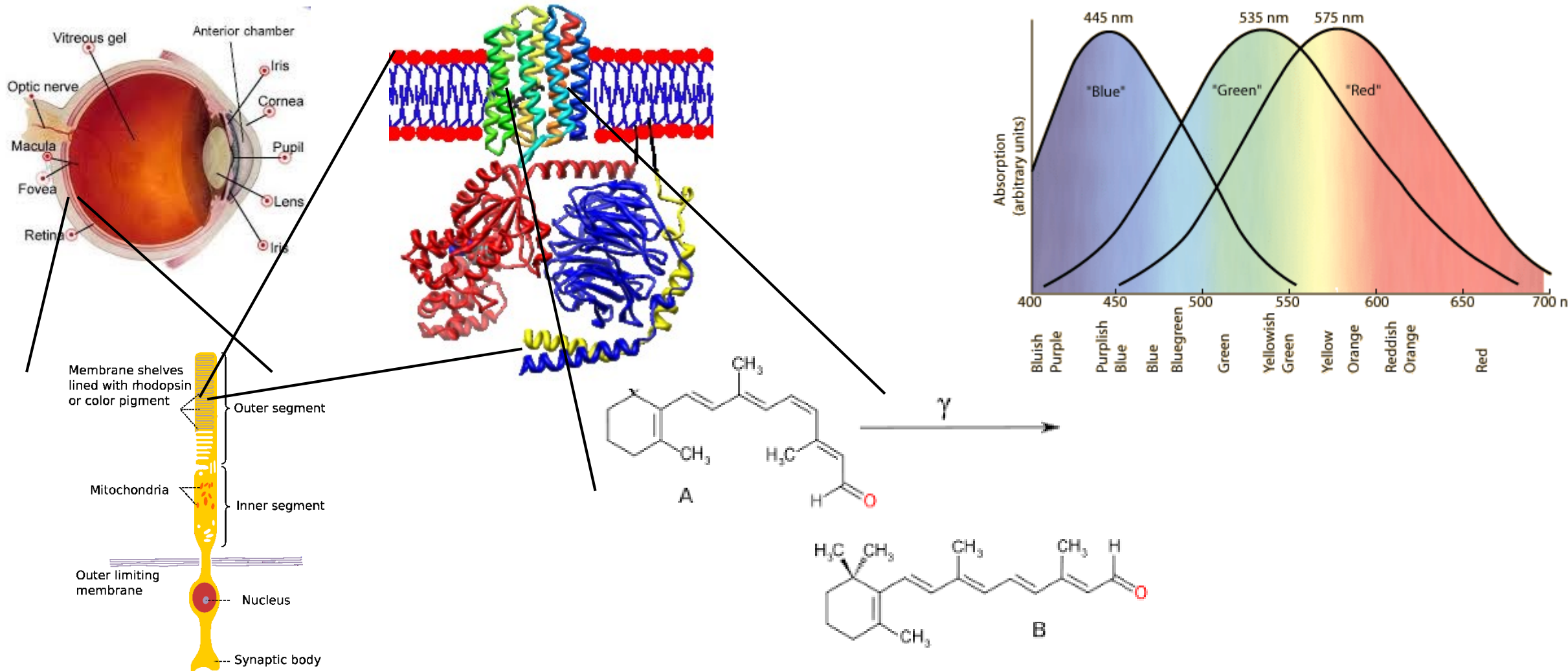
- Photon absorption is all or nothing
- Conservation of energy says that however much energy is lost ( $hc/\lambda$ ) is gained by the matter
- Photon energy goes into chemical, electronic, kinetic, or thermal energy
- Photons get created by oscillating charge, and that energy is lost by the matter





# How is light detected

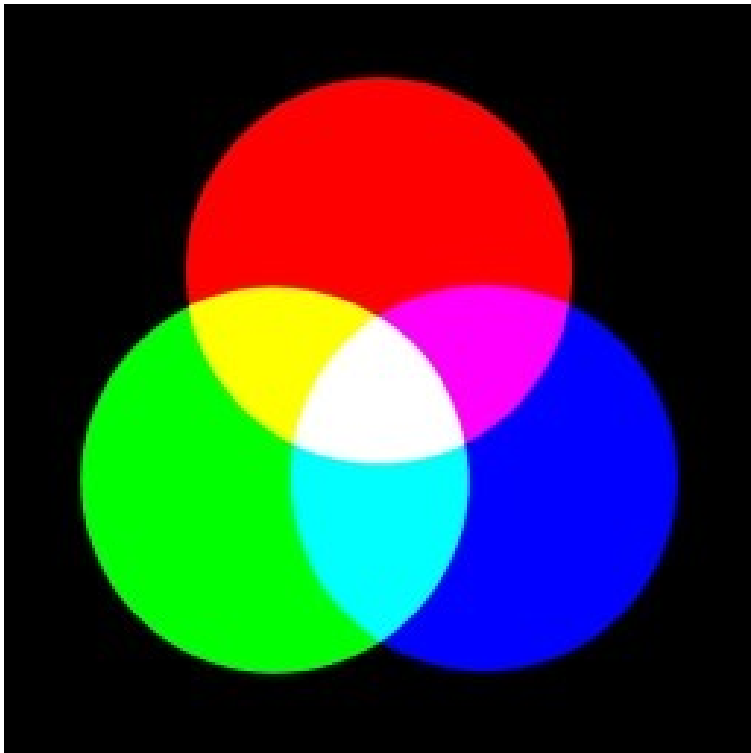
- Rhodopsins in the eye: isomerization  $\rightarrow$  conformational change  $\rightarrow$  G protein activation



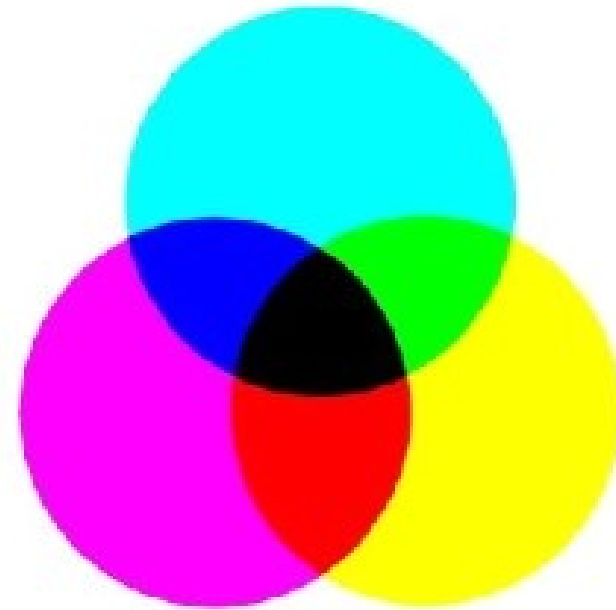


# Colors addition and absorption

Color addition



Color subtraction



# How light is detected

- Photodetector– light is absorbed by a semiconductor, energy converted to electron/hole pair

Metal Oxide Semiconductor (MOS) Capacitor

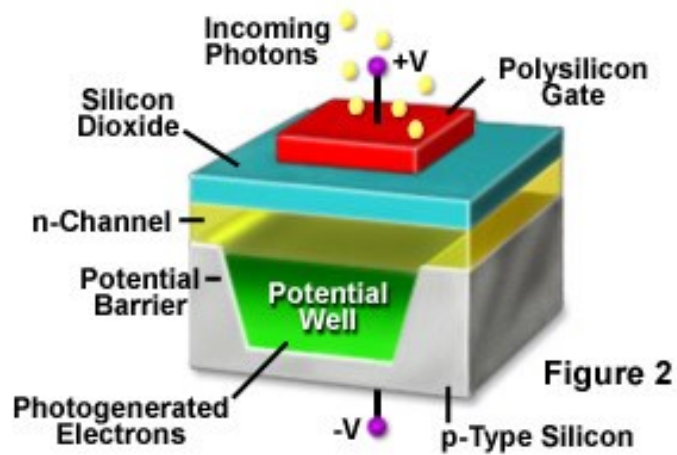
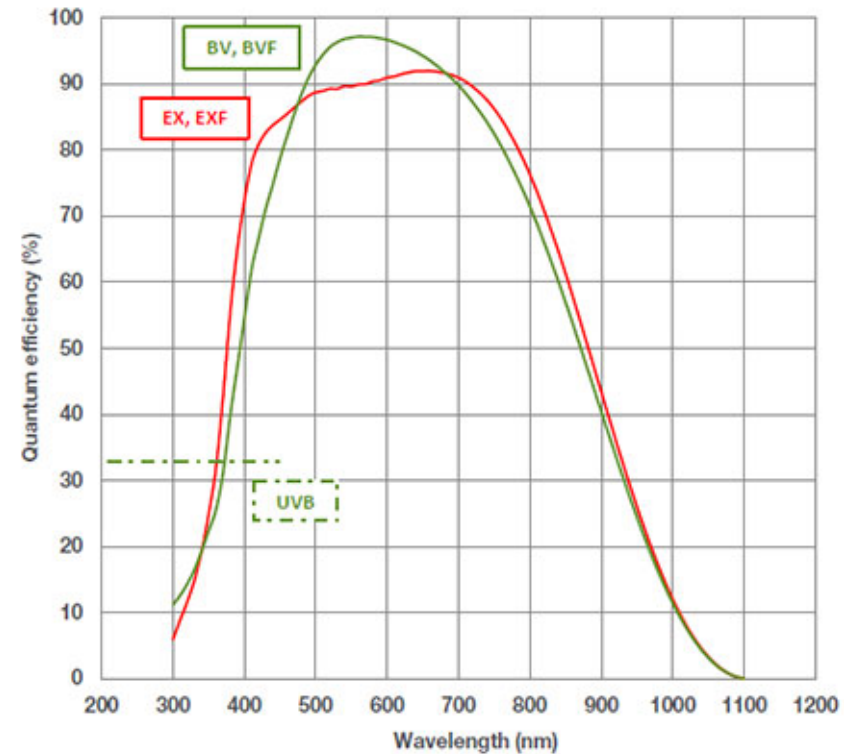
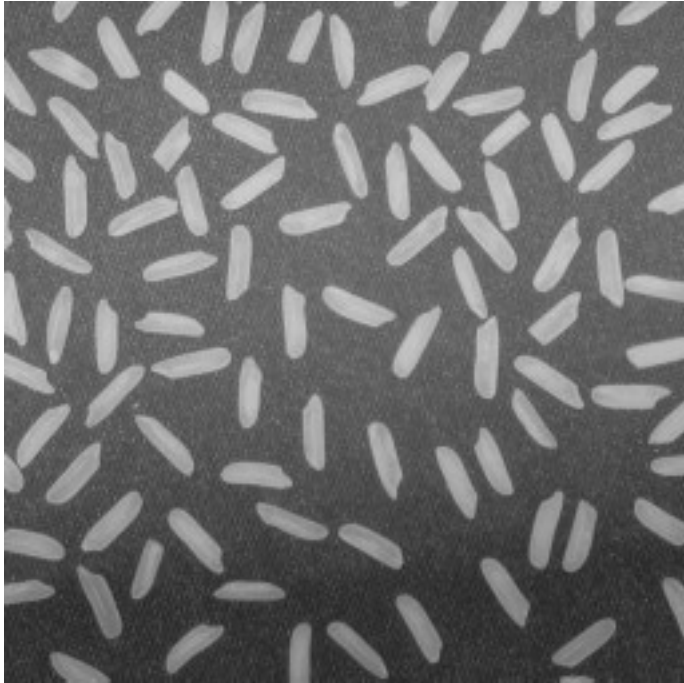


Figure 2



Andor iXon 897 emCCD  
Silicon detector

# Digital Images

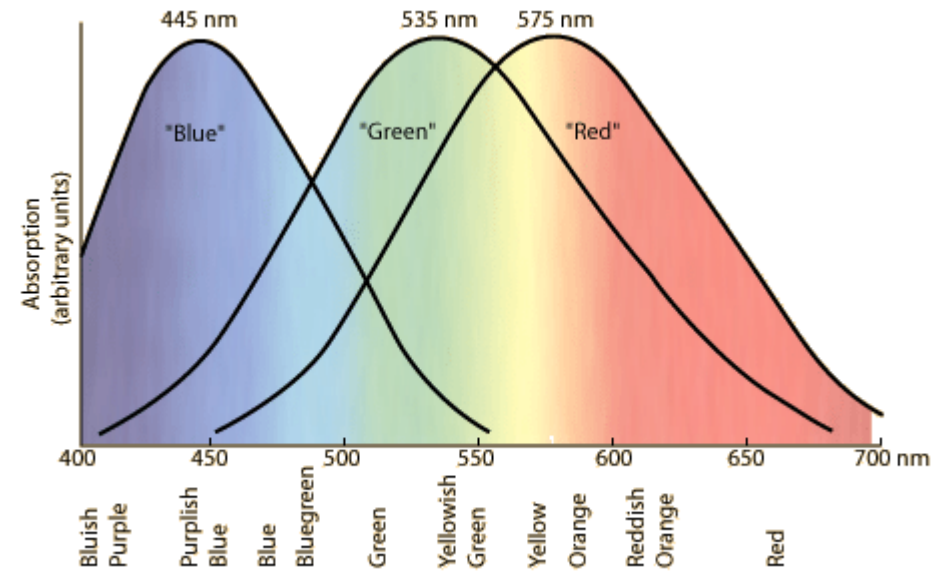
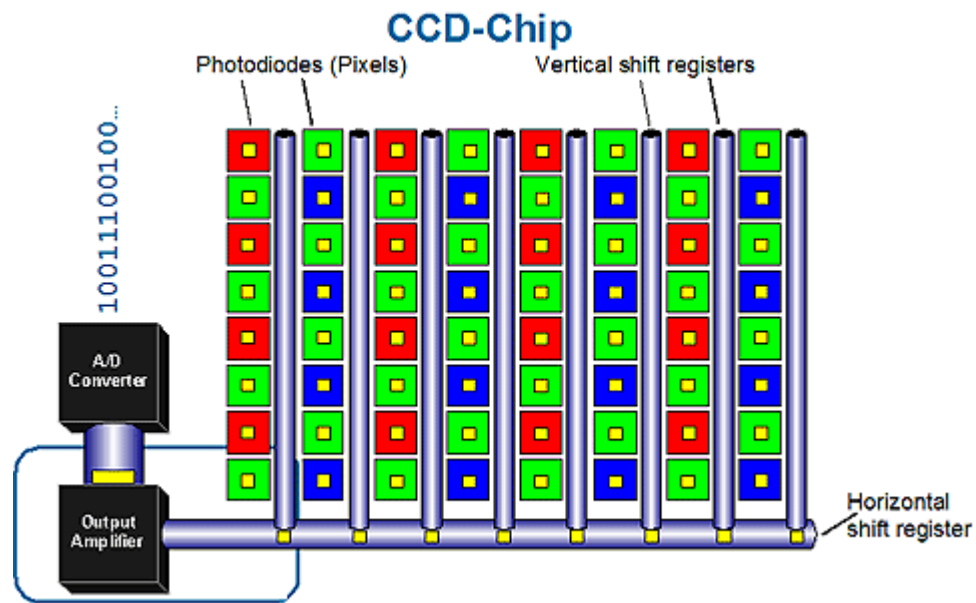


122	92	95	99	102	107	89	90	95
99	99	102	82	100	89	91	87	86
97	107	103	86	98	92	93	96	96
102	100	99	87	97	89	110	95	93
84	107	98	99	92	94	104	91	104
86	107	93	107	91	109	92	105	91
97	104	90	93	93	96	89	121	100
105	102	110	97	100	93	89	106	102
111	97	100	95	110	98	103	105	93
97	88	114	93	96	87	101	94	102
100	95	100	101	97	95	101	95	115
91	105	106	101	97	97	101	96	103
87	110	105	105	89	100	89	97	100
91	98	92	108	93	98	98	95	90
105	90	94	99	105	98	90	99	87 ...
111	95	103	95	94	91	93	98	91
99	110	91	89	95	87	95	99	108
103	110	89	88	95	94	91	103	110
97	116	88	99	95	94	102	99	100
94	104	89	98	105	101	103	106	96
107	100	94	95	101	95	97	98	97
133	96	99	99	94	100	105	92	95
178	124	104	89	97	91	122	93	98
171	171	105	94	100	99	103	95	100
168	171	157	106	91	108	103	93	102
172	171	177	131	88	104	101	93	92
175	172	177	174	108	102	97	100	93
176	173	176	175	155	96	104	106	98
184	179	178	174	177	135	107	92	94
187	182	178	177	177	175	113	93	105

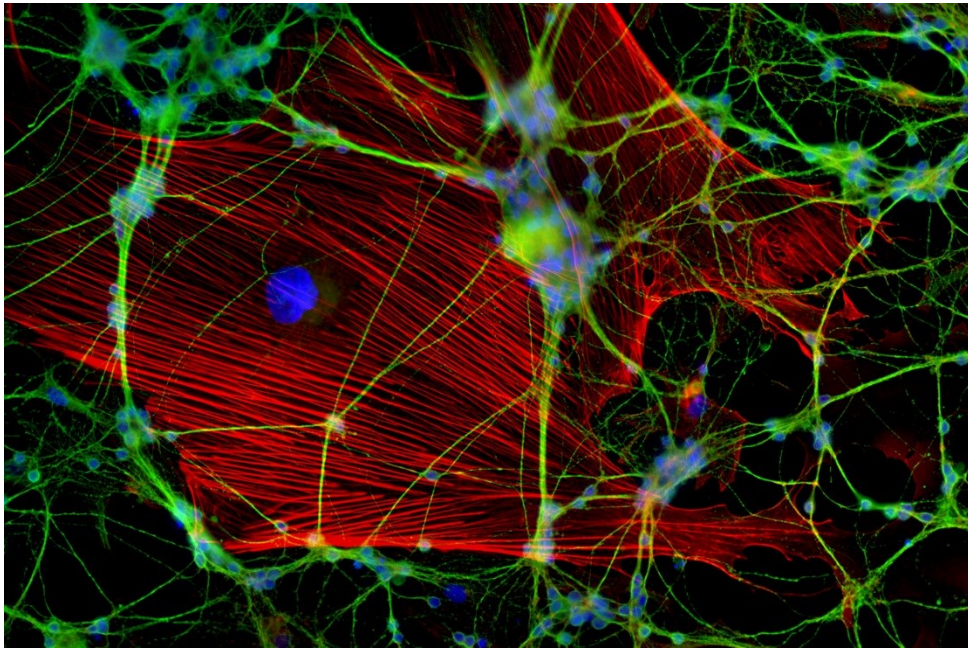
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# Color images

- No such thing as a color camera
- Lists of RGB per pixel



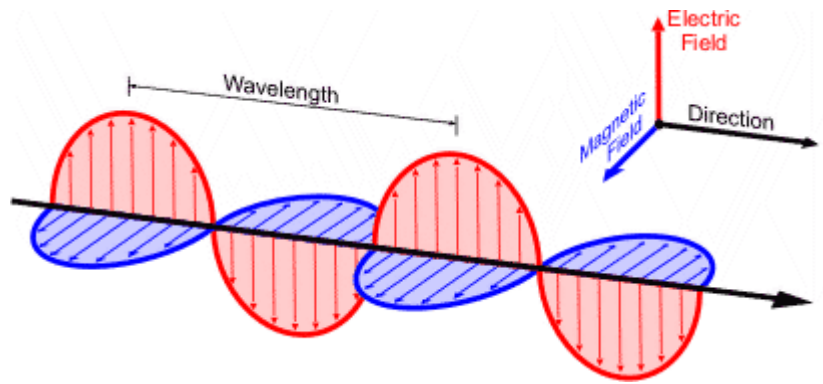
# Color digital images



5	23	56	82	124	110
7	27	57	86	124	106
15	36	64	95	127	101
18	37	65	97	125	98
14	32	63	95	121	98
15	32	72	98	120	100
11	31	83	101	116	101
3	26	89	103	118	106
1	3	1	0	6	8
0	2	0	0	7	5
1	5	2	4	8	1
0	3	0	5	7	0
0	0	0	4	6	1
1	4	16	14	9	6
9	15	38	26	12	12
4	13	46	30	12	12
0	0	7	7	18	19
0	0	6	8	15	13
0	0	5	11	10	1
0	1	4	10	5	0
0	0	8	9	3	0
0	3	19	14	2	0
0	2	32	20	0	0
0	0	37	21	0	0

# Properties of EM waves

# Properties of light – propagating EM wave



## Waveforms of Electromagnetic Radiation States

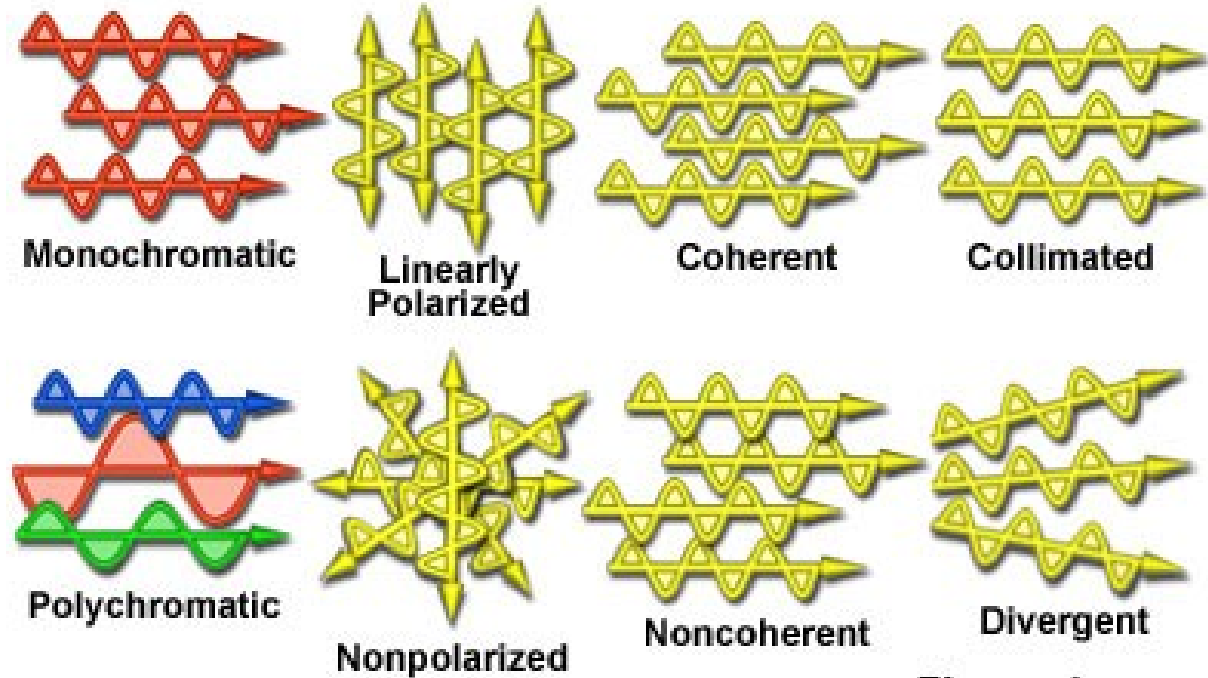
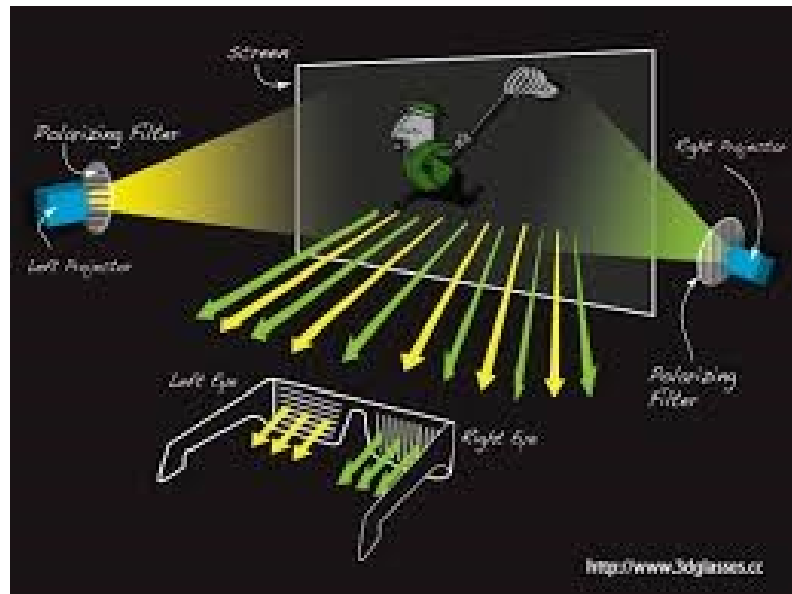


Figure 4





On to Matlab...