物質機能科学IIb

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知覚情報科学

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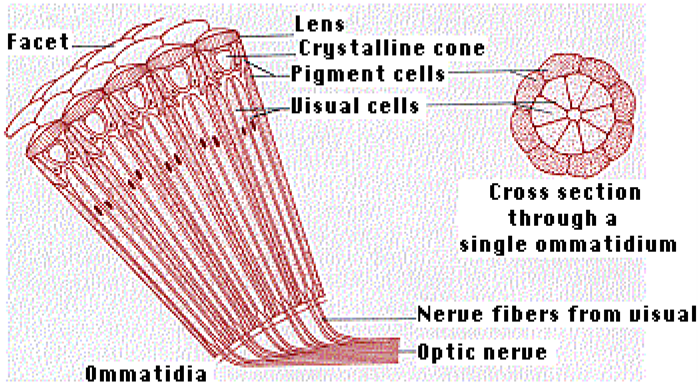
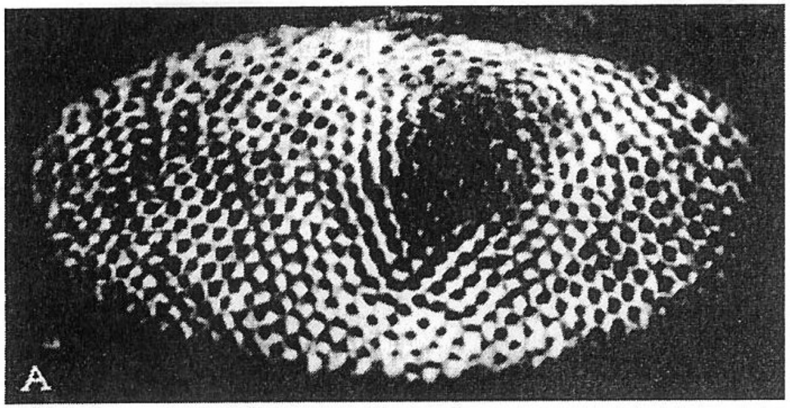
(12-13)

後期２００９年

The COMPOUND EYE





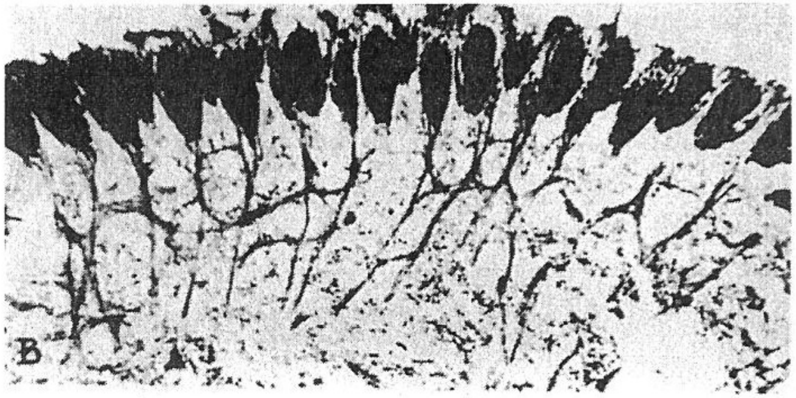
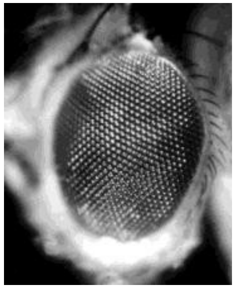


Fig. 36–11. The compound eye of the horseshoe crab. (a) Normal view. (b) Cross section.



r=3mm

λ=400nm

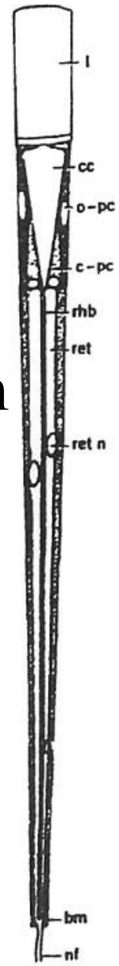


Fig. 36–7. The structure of an ommatidium (a single cell of a compound eye).

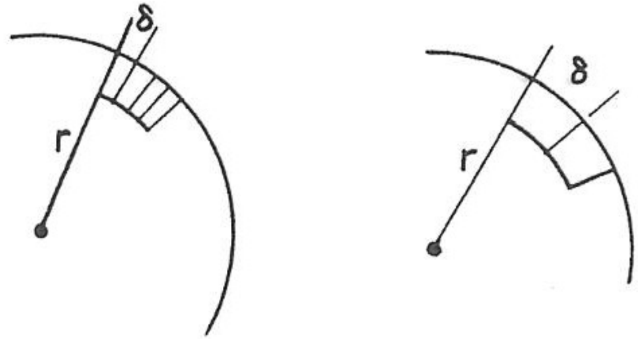


Fig. 36–8. Schematic view of packing of ommatidia in the eye of a bee.

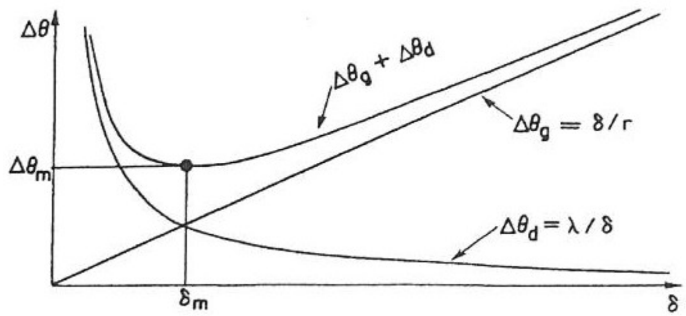


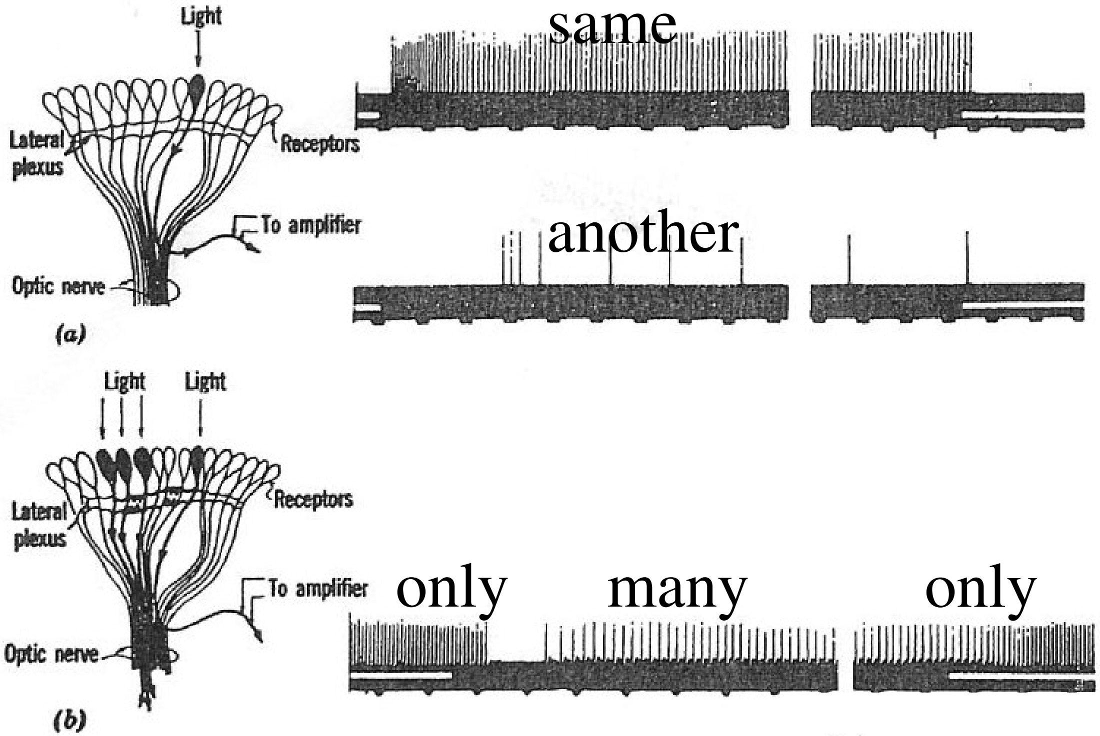
Fig. 36–9. The optimum size for an ommatidium is δ_m.

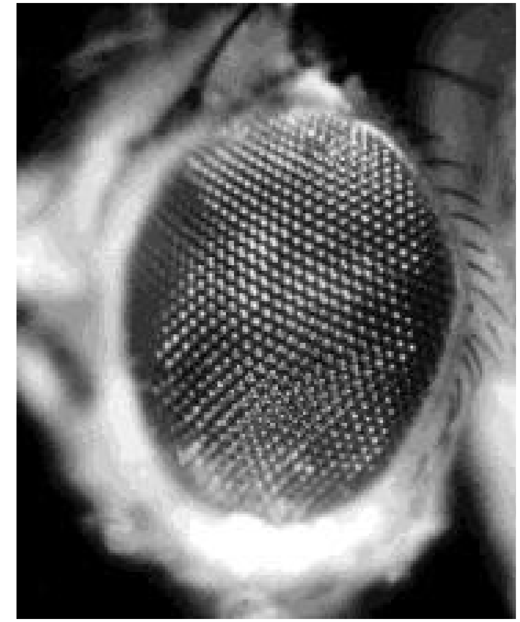
$$\Delta\theta_g = \delta/r.$$

$$\Delta\theta_d = \lambda/\delta.$$

$$\delta = \sqrt{\lambda r}.$$

$$\frac{d(\Delta\theta_g + \Delta\theta_d)}{d\delta} = 0 = \frac{1}{r} - \frac{\lambda}{\delta^2},$$





Edge enhancement!

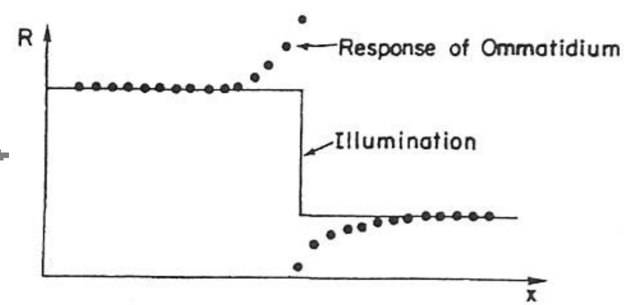


Fig. 36–13. The net response of horseshoe crab ommatidia near a sharp change in illumination.

Types of response in optic nerve fibers of a frog

Type	Speed	Angular field
1. Sustained edge detection (nonerasable)	0.2–0.5 m/sec	1°
2. Convex edge detection (erasable)	0.5 m/sec	2°–3°
3. Changing contrast detection	1–2 m/sec	7°–10°
4. Dimming detection	Up to $\frac{1}{2}$ m/sec	Up to 15°
5. Darkness detection	?	Very large

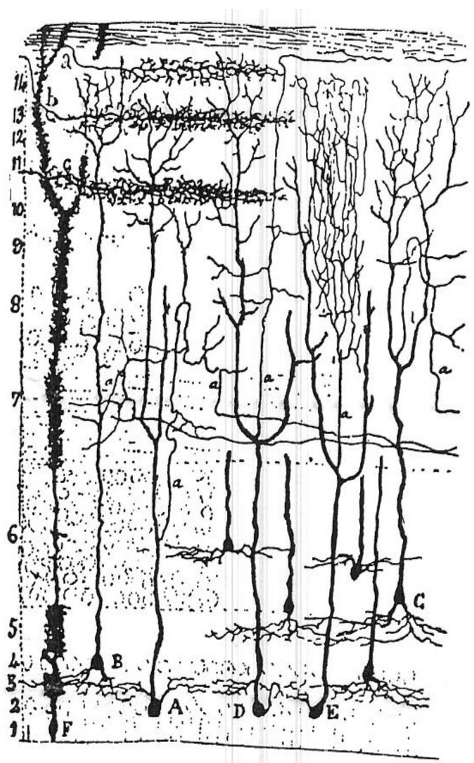
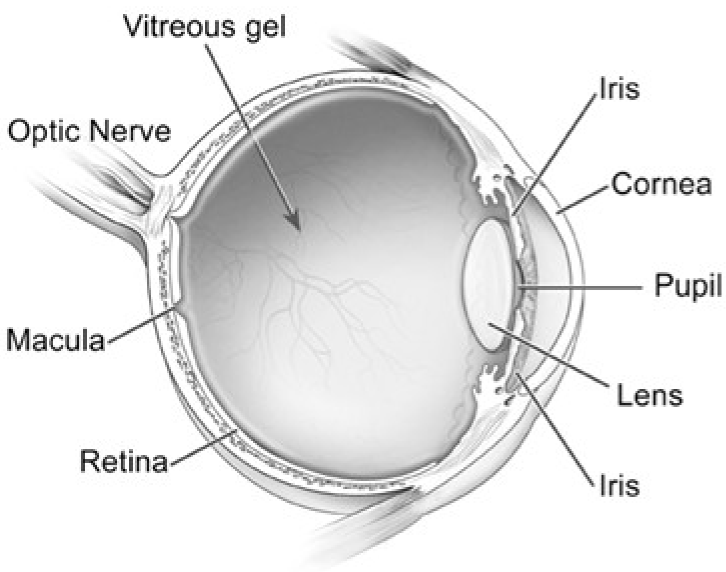
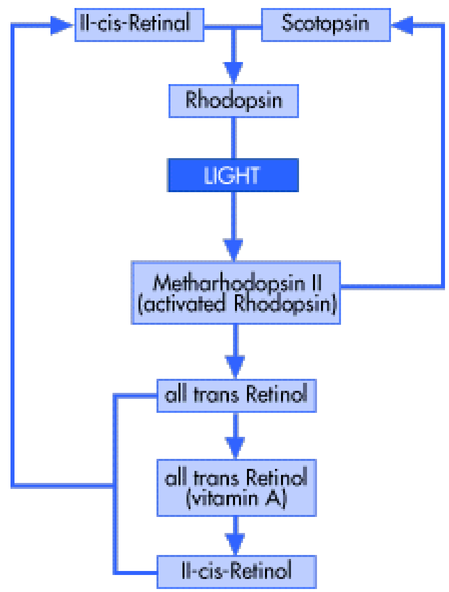
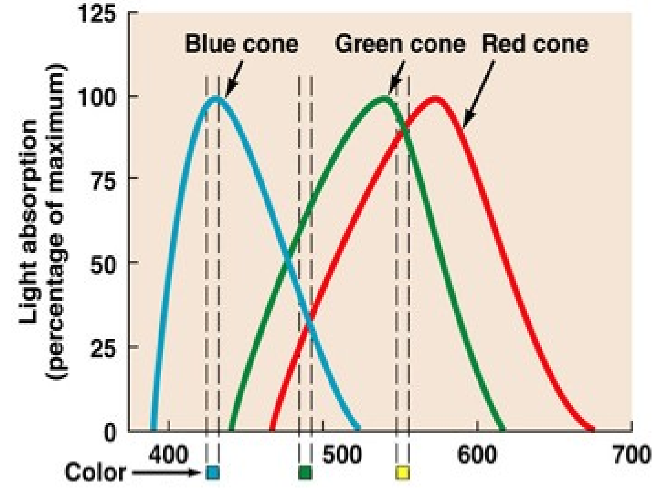


Fig. 36–14. The tectum of a frog.







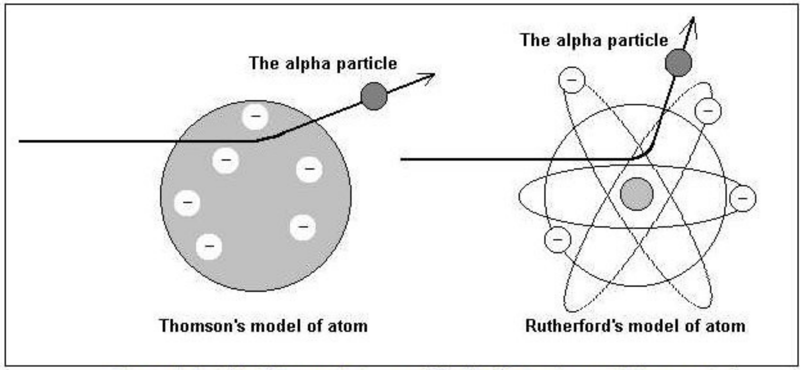
“RGB”の色で全部の色を作る。この事は光の特性ではない、人間の目の特性です（！）

人間は 「Trichromatic Vision」

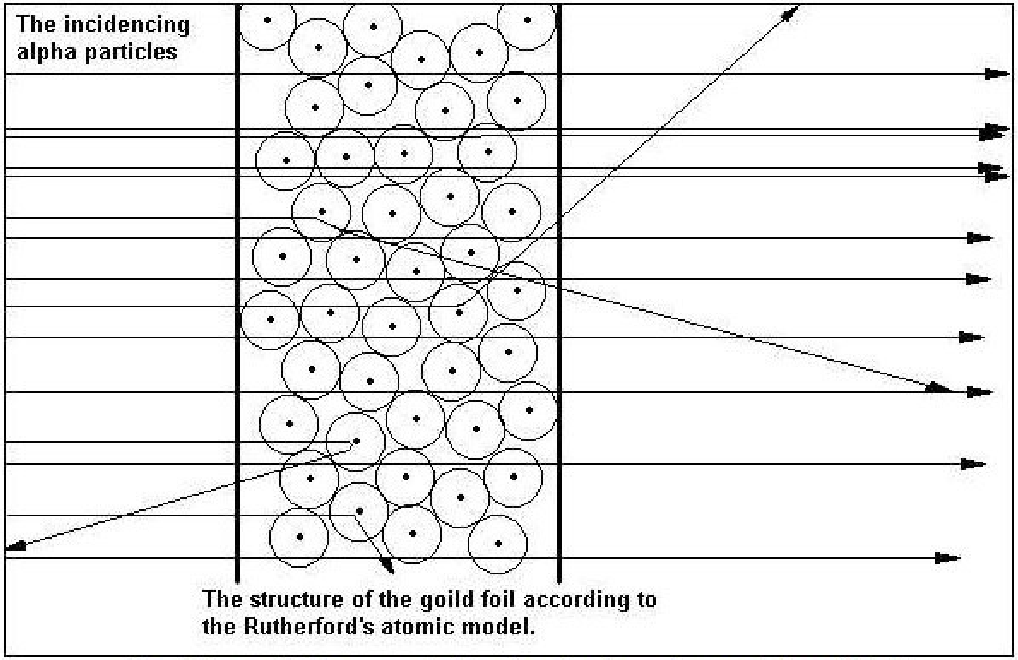
動物の世界の中に「Tetrachromacy」「Pentachromats」などがあります

Solid state photodetection (Artificial Vision):

The Rutherford Experiment (1909)



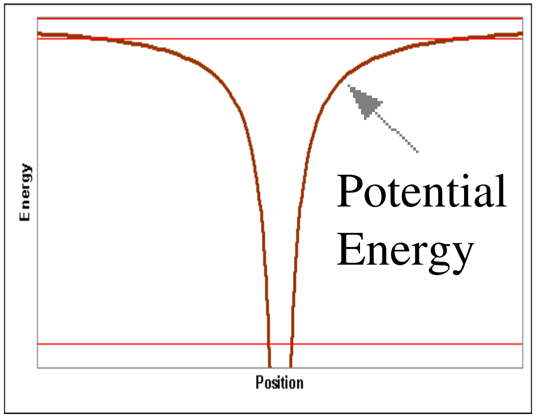
The models of the Thomson's atom and Rurtherford's atom; and the expected aberrations of alpha particle in both cases.



The alpha particles propagated on the atomic nucleuses of the gold foil.

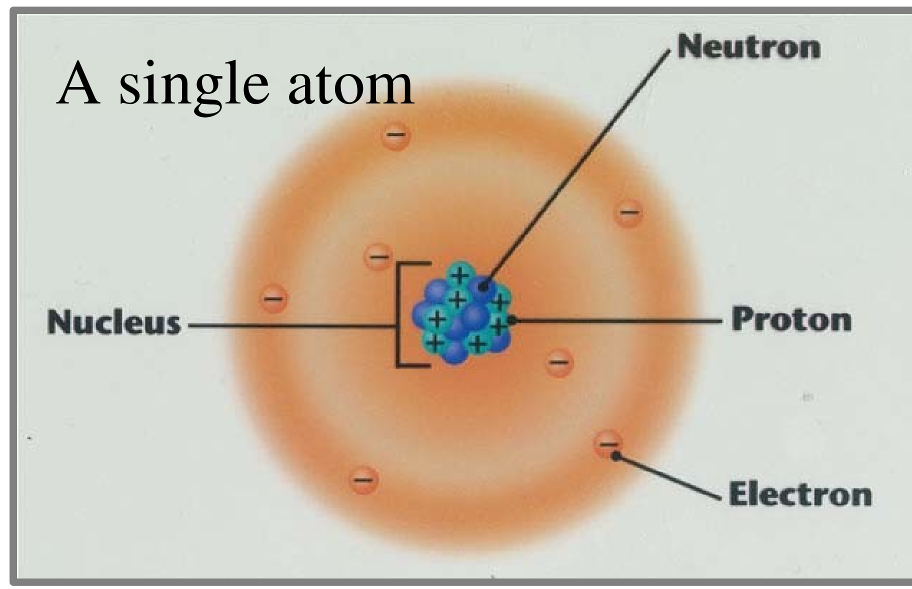
The experiment showed that there are some not much abberated alpha particles but also some abberated of a very big angle (135-150 degree). That occurrence couldn't be explained by some small, added aberrations. Experimental data proved the "planetary" model of atom.

SOLID STATE photodetection



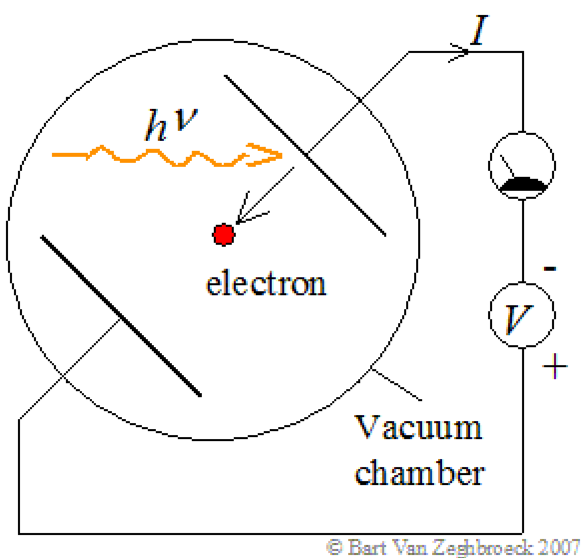
Energy level

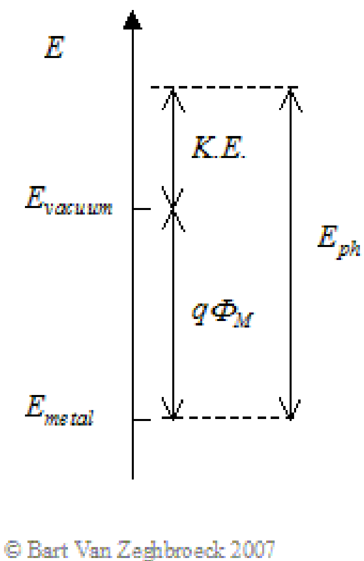
$$\bar{E} = \frac{-q}{4\pi\epsilon_0 R^2}\hat{r}$$

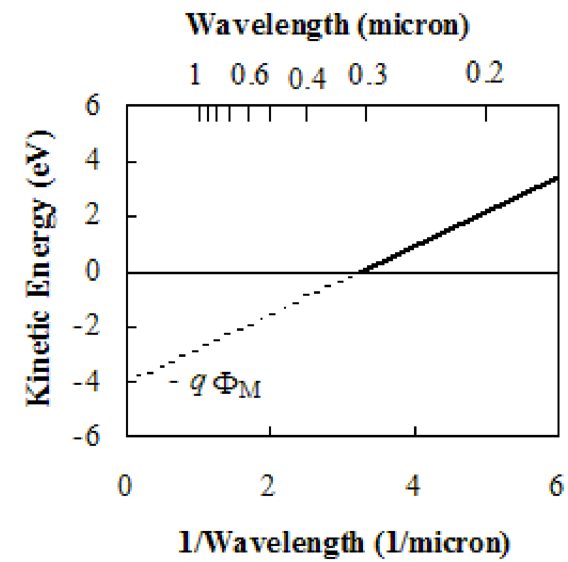


- Electron energies are are quantized
- Only two electrons are allowed to occupy an energy level
- One of these electron will have spin up and the other will have spin down.
- Electrons that are more tightly bound are more likely to be found closer to the nucleus
- We build atoms by filling energy levels from the most negative to the least negative

The photo-electric effect

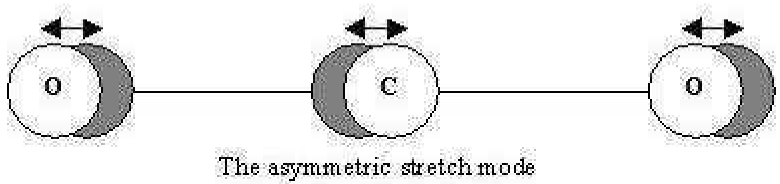






Light intensity-> photon FLUX
Light Color (frequency)-> photon Energy

$$E_{ph} = h\nu = \frac{hc}{\lambda}$$



A solid: many atom

- Crystalline solids are collections of atoms arranged in a repetitive three-dimensional structure.

- The energy levels in solids become grouped into "bands" which are separated by "gaps".

- Electrons cannot have energies that would fall into the gaps.

- The highest lying band containing filled states (as T --> 0) is called the valence band.

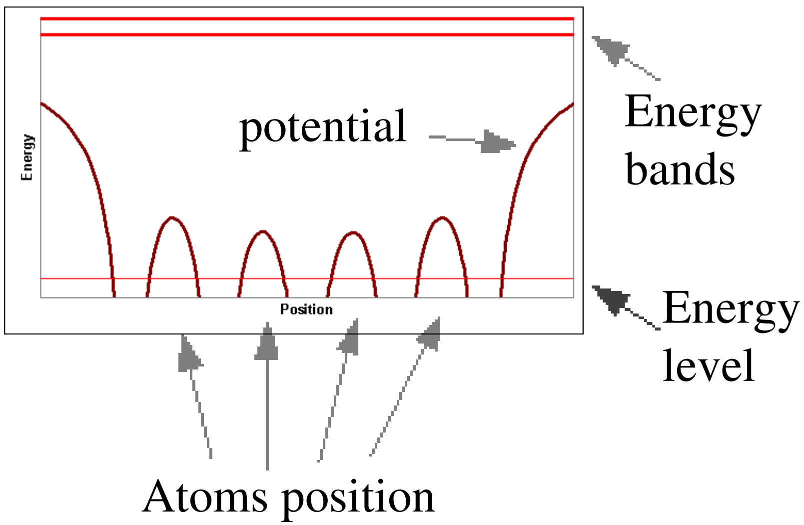
- The lowest lying band band containing empty states (as T --> 0) is called the conduction band.

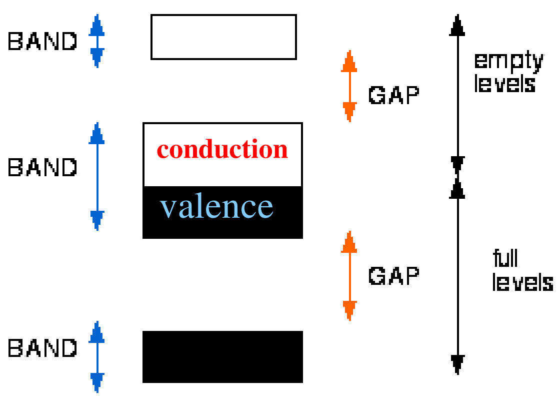
- There are three types of solids:

metals

insulators

semiconductors



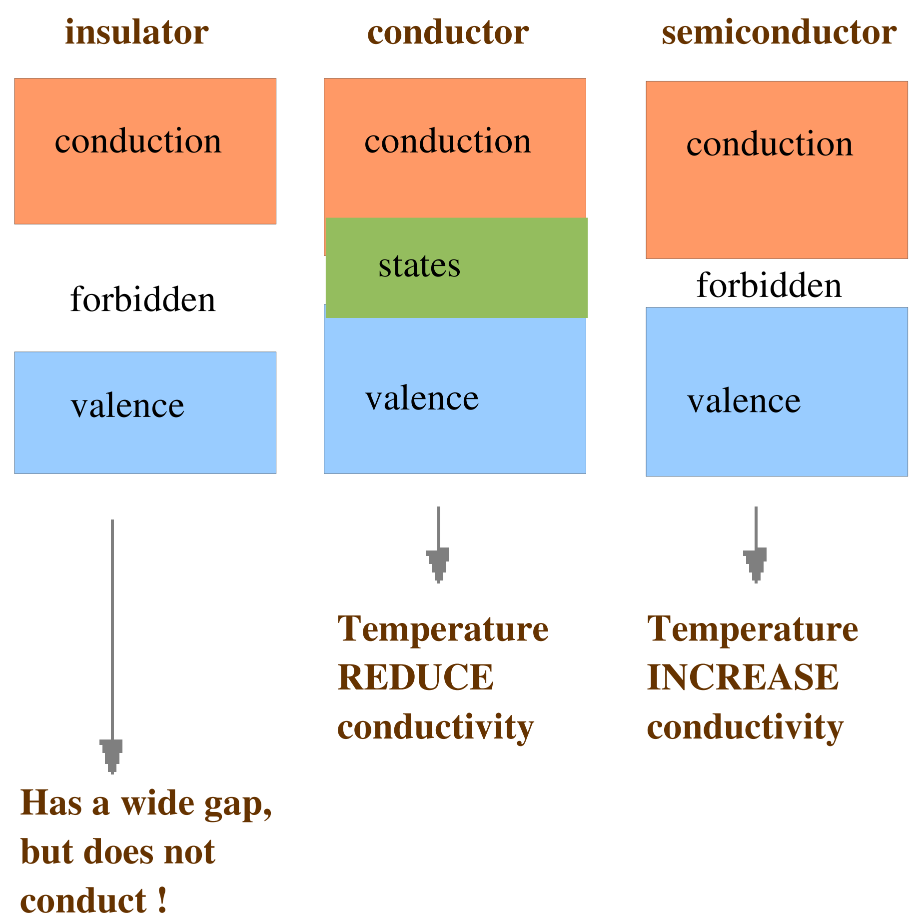


In an **insulator**, the valance band is totally occupied, but the conduction band is empty. The amount of energy electrons can gain from thermal agitation is not enough to lift them from the valence band into the conduction band. The energy gap is too large. No current can flow.

In a **conductor**, the valance band is totally occupied, but the conduction band is only partially occupied. Electrons can be accelerated by an electric field and current can flow.

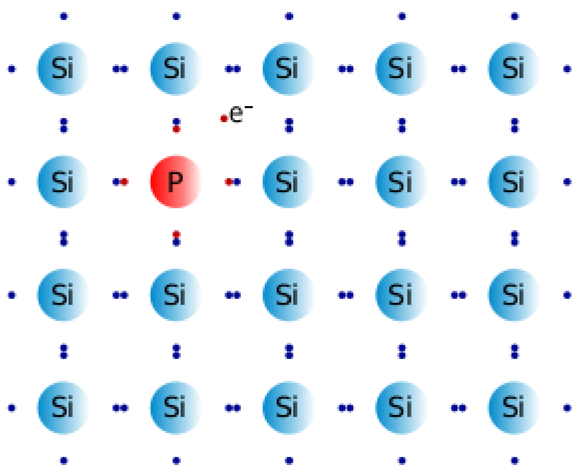
In a **semiconductor** the energy gap between the valence and the conduction band is small, and at higher temperatures some electrons can gain enough energy from thermal agitation to lift them from the valence band to the conduction band. The valence band now contains **holes**, i.e. some states in that band are empty, and the conduction band is no longer totally empty, but contains some electrons. Both bands can contribute to the conduction of current, but the conductivity is low, because the number of unoccupied states in the valence band and the number of occupied state in the conduction band is small.

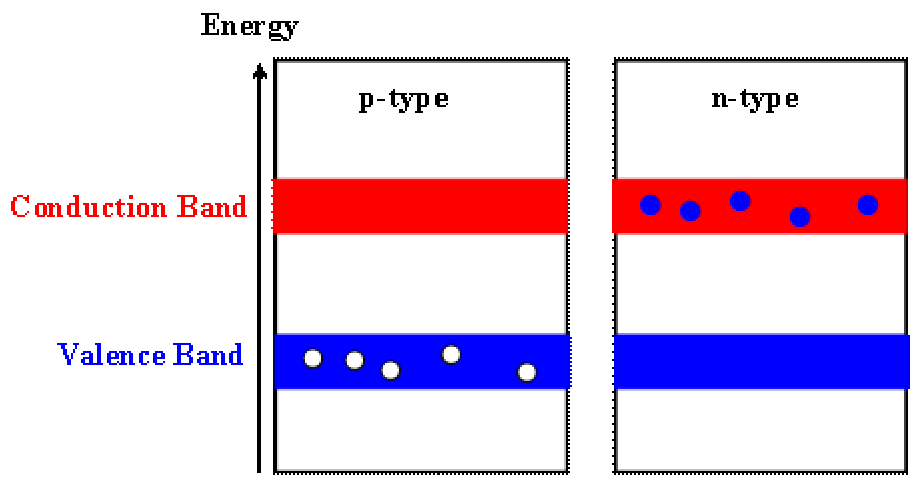
We search WIDE band-gap to emit higher energies (shorter wavelengths)

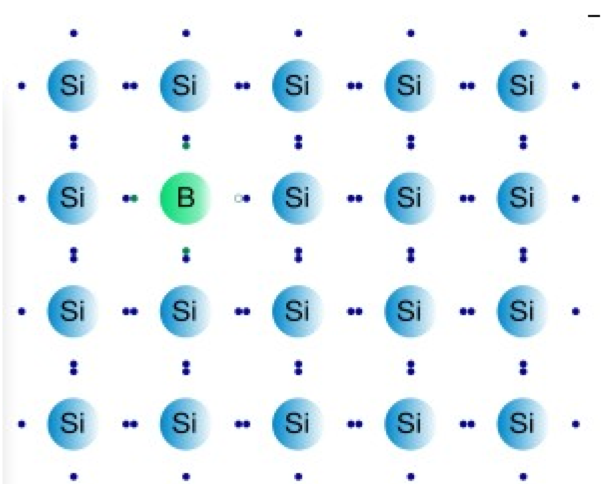


DOPING

n-type







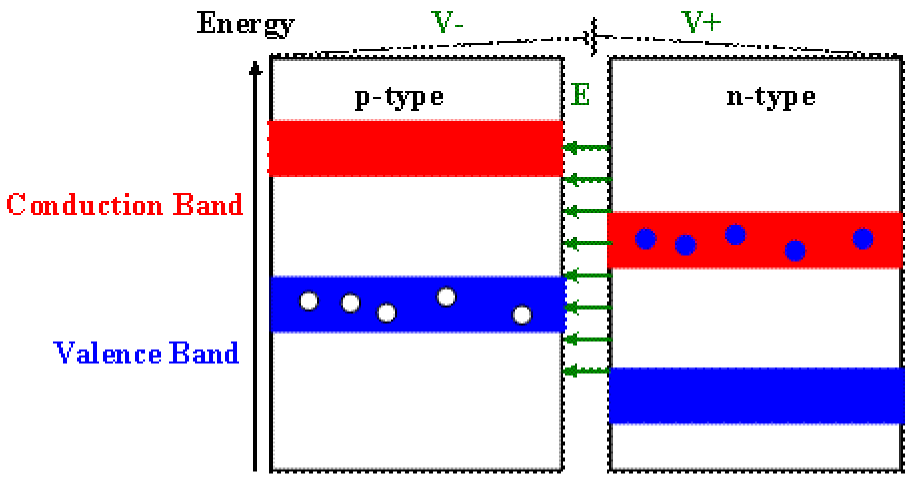
p-type

The addition of impurities in a p-type semiconductor creates some holes in the valence band. The addition of impurities in a n-type semiconductor puts some electrons in the conduction band. The holes in the valence band of the p-type material and the electrons in the conduction band of the n-type material can have net movement through the material and we call them free carriers. The doped material can conduct current.

Doping introduces no charges (total is ZERO) !
However, it introduces "carriers". We can have a wide band-gap and conduct current !

How does a voltage affect the energy levels?

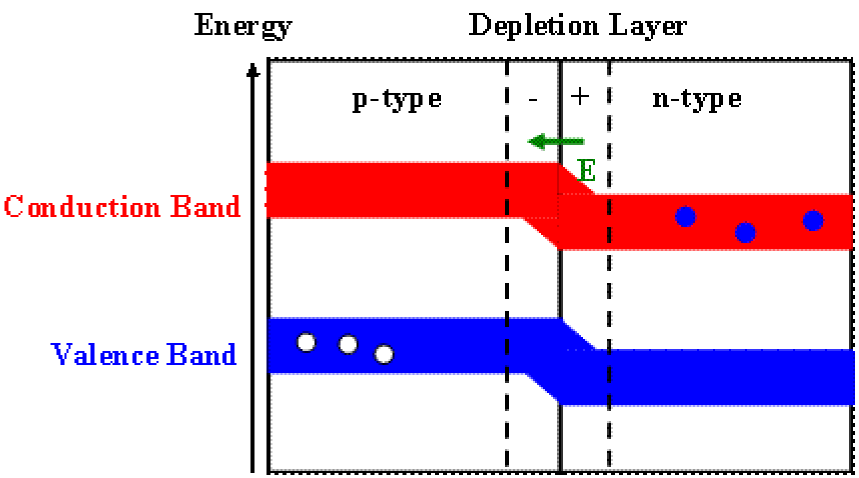
Assume you established an electric field between the two semiconductors. Assume they are not in contact and no current flows.



If the field points from the n-type to the p-type semiconductor, then the potential is higher in the n-type semiconductor, and the potential energy of the electrons is higher in the p-type semiconductor. (Electrons are negatively charged and their potential energy has the opposite sign as the potential.)

A PN junction photodiode

The simple model presented here mixes a quantum mechanical with a classical description. Assume you bring a n-type and a p-type semiconductor in contact with each other.

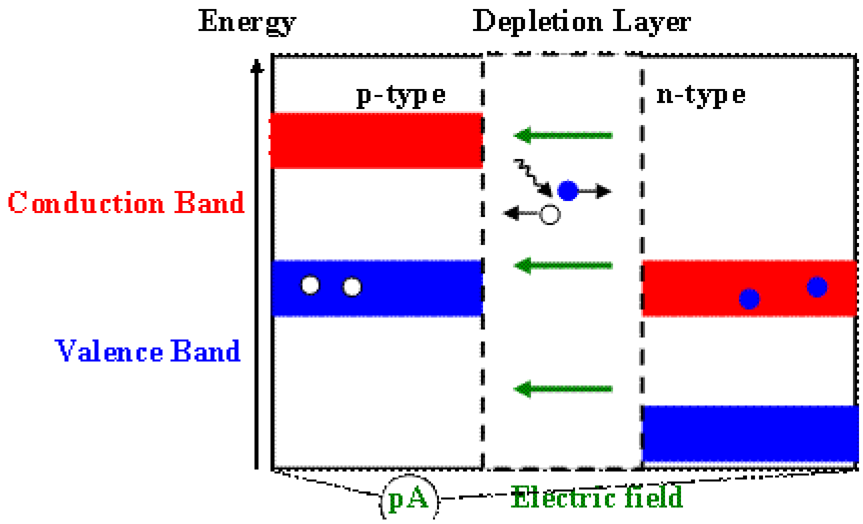


Electrons in the n-type semiconductor fill some of the holes in the p-type semiconductor because these holes are available lower-energy states. This leaves positively charged cores in the n-type and extra negatively charged electrons in the p-type semiconductor material. The n-type semiconductor becomes positively charged and the p-type semiconductor becomes negatively charged.

The charge on each doped semiconductor repels the free carriers in the other doped semiconductor. The free carriers move away from the junction. A **depletion layer** free of mobile electrons and holes forms. An electric field points from the n-type to the p-type semiconductor in this depletion layer. This is equivalent to an applied voltage as in the previous figure.

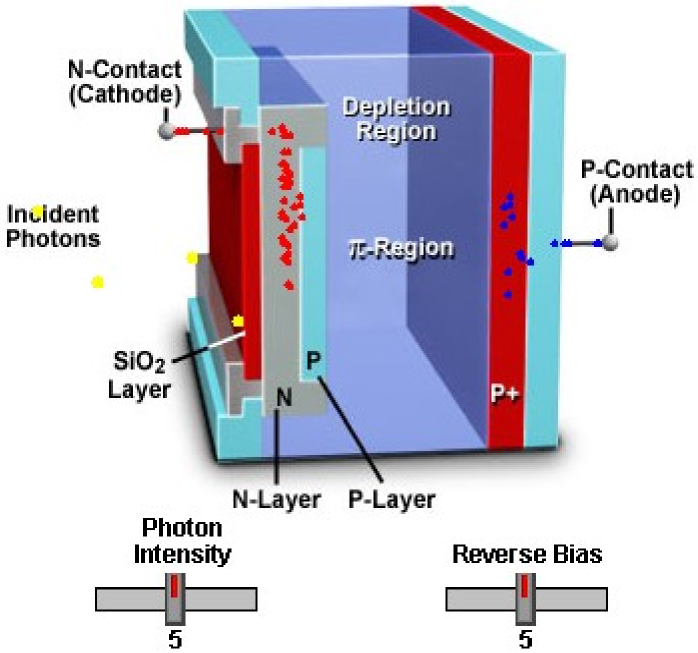
The energy bands in the p-type semiconductor move up and the energy bands in the n-type semiconductor move down. When the energy of the states in the conduction band of the n-type semiconductor is equal to the energy of the states in the valence band of the p-type semiconductor, lower lying energy states are no longer available for the electrons in the conduction band of the n-type semiconductor, and the filling of the holes stops

Exposing to LIGHT !



If a photon strikes the PN junction and creates an free electron-hole pair in the depletion layer, then the electron will be accelerated towards the n-type and the hole towards the p-type side. If many photons create electron-hole pairs, a meter connected across the junction will register the flow of a small current. This current crosses the junction from the n-type to the p-type material.

Avalanche photo diode



An avalanche photodiode is a silicon-based semiconductor containing a p-n junction consisting of a positively doped p region and a negatively doped n region sandwiching an area of neutral charge termed the depletion region. These diodes provide gain by the generation of electron-hole pairs from an energetic electron that creates an "avalanche" of electrons in the substrate.

Fundamental Equations:

Optical intensity

Optical power

Area

$$\Phi = \frac{P}{\hbar\omega} = \frac{IA}{\hbar\omega}$$

Photon flux

pulsation

Counts

Quantum efficiency

$$N(t) = \eta \Phi t$$

power

Count rate

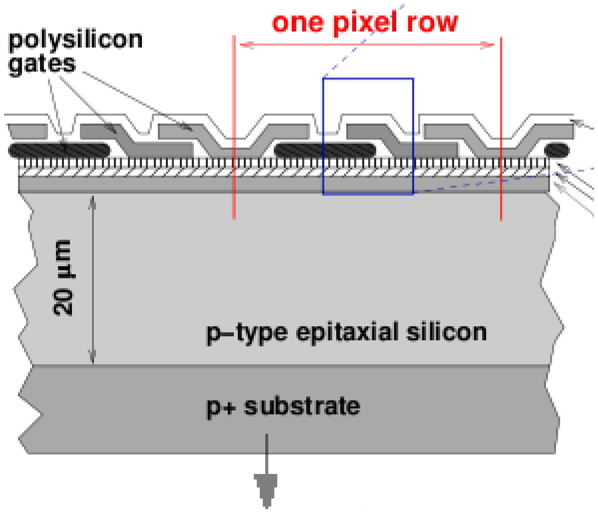
$$R = \frac{N(t)}{t} = \eta \Phi = \frac{\eta P}{\hbar\omega}$$

time

Planck's constant

The CCD camera

Photo



Pixel image