Biology, Exploring The Diversity of Life, Volume 1

Ch 1: Light and Life

- A **cataract** is a change in the lens of an eye, making it more opaque.
    - The underlying cause is a progressive denaturation of one of the proteins that make up the lens
    - Increased opaqueness of the lens absorbs certain wavelengths, decreasing the transmittance of blue light.

Ch 1.1 The Physical Nature of Light

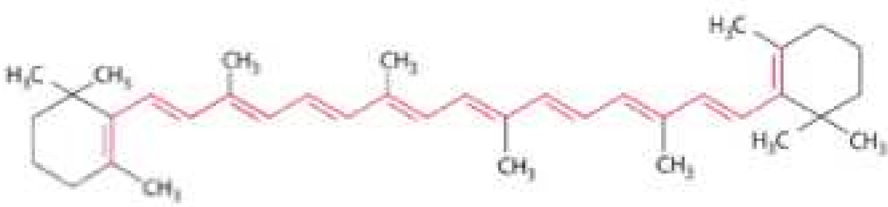
- Light serves 2 functions on Earth:
    - Source of energy that sustains all life
    - Provides organisms with info about the physical world
- Green algae **Chalmydomonas reinhardtii** is a single celled photosynthetic eukaryote that is commonly found in ponds & lakes.
    - Each cell contains a large chloroplast that harvests light E and uses it to make E rich molecules thru photosynthesis.
    - Contains light sensor or **eyespot** that allows it to sense both light & light intensity.

Ch. 1.1a What is Light?

- Light can be defined as the portion of the electromagnetic spectrum that humans can detect.
- Light/visible radiation spans the wavelengths: 400 nm (blue) to 700 nm (red)
    - Wavelengths outside this range should be referred to as UV & infrared radiation.
- Light behaves as a wave & stream of E particles known as **photons**.
    - Photons have no mass but contain a discrete amount of E
    - E in photon is inversely proportional to its wavelength.

Ch. 1.1b Light Interacts with Matter

- When photons hit an object they are either:
    - Reflected, transmitted though, or absorbed.
- To be used by an organism, light must be absorbed.
    - Molecules called **pigments** absorb photons of light at different wavelengths for different pigments.
- Pigments are able to absorb photons b/c they embody a region where carbon atoms are covalently bonded with alternating single & double covalent bonds.
    - Called a conjugated system resulting in the delocalization of electrons so they are not closely associated with any atoms to allow interaction with photons.

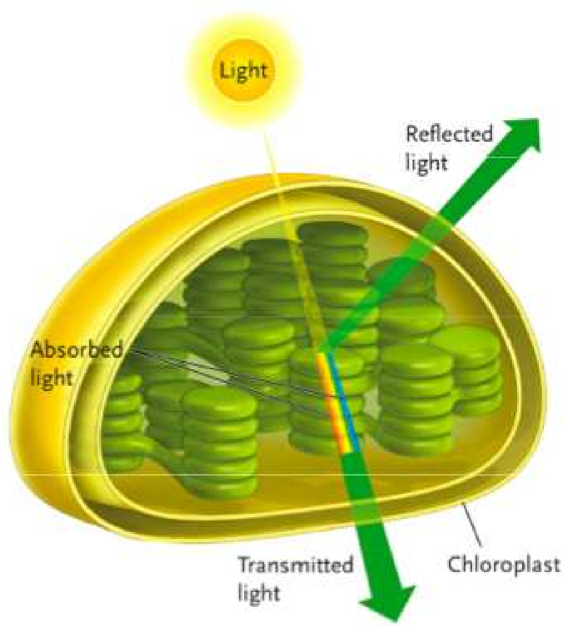


Beta-carotene

Ch. 1.1 c Why is Chlorophyll Green?

- Light absorption occurs when the E of a photon is transferred to an electron of a pigment.
    - Upon absorption of a photon, the E is transferred to the electron moving it from ground state to a higher, excited state.
- The photon absorption in a chlorophyll molecule can exist in only 2 E states for the electron.
    - The lower excited state is accomplished by a red photon of light compared to the higher excited state brought on by blue photons as they embody more E.

- Green photons cannot be absorbed b/c chlorophyll does not have an E state matching the E in a green photon; instead they are transmitted thru the pigment or reflected giving chlorophyll its green color.
    - Color of pigment is determined by the wavelengths it cannot absorb.
    - Colour of plant is determined by what pigment it has
- An **action spectrum** is a plot of the effectiveness of different wavelengths of light on a biological process.
    - Ex, action spectrum for chlorophyll a pigment displays that red and blue light proves to be more effective at driving photosynthesis.



Ch 1.2 Light as a Source of Energy

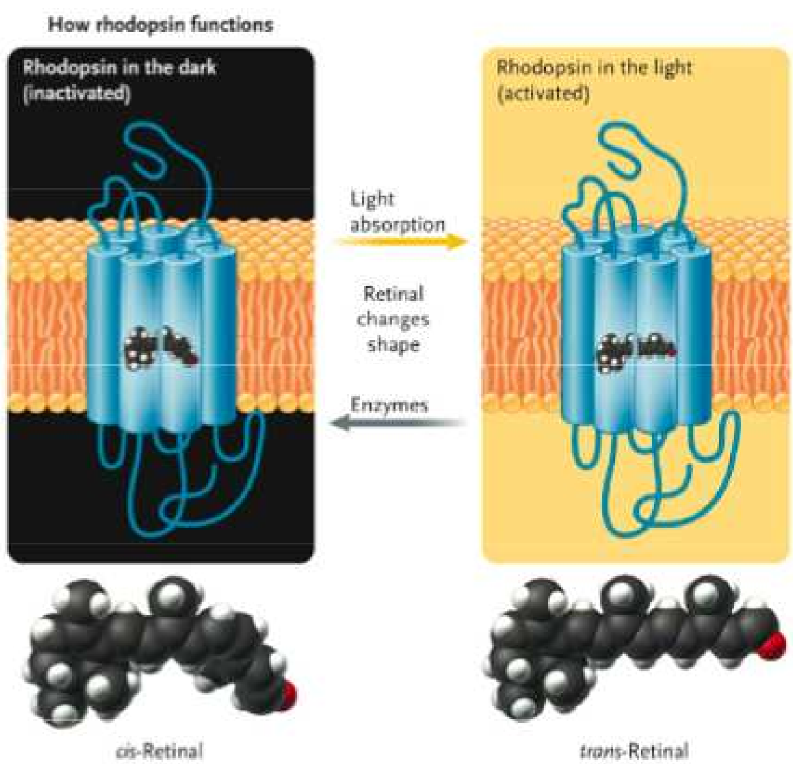
- An electron in a higher state is a source of potential E that can be used to do work.
    - Ex. In photosynthesis, the potential E is used in photosynthetic electron transport to synthesize E rich compounds like NADPH & ATP, both of which are used to convert CO2 into carbs.

- This E can also be used to synthesize biological molecules including lipids, proteins or nucleic acids.
- Halobacterium contain a protein complex called bacteriorhodopsin, that functions as a light-dependent proton pump.

Ch. 1.3 Light as a Source of Information

Ch 1.3a Rhodopsin, a Highly Conserved Photoreceptor

- Photoreceptors are the basic light sensing structures in all organisms
- Most common PR is rhodopsin used by various organisms
  - Rhodopsin molecules contain a protein called **opsin** that binds a single pigment called retinal.
  - Opsins are membrane proteins spanning a membrane multiple times & form a complex with the retinal molecule at the center.
  - Absorption of a photon causes the retinal pigment to change shape(cis at rest to trans), triggering alterations to the protein opsin, triggering alterations in intracellular ion concentrations & electrical signals.



- Electrical signals are then sent to the brain via the optic nerve (bundle of nerve fibres that needs to get to the brain, once it exits the retina, there are no PR, that portion in the visual field is thus not being detected, therefore other eye compensates for blind spot, different positioning); in humans light capturing involves 125 mill PR cells (rods & cones) lining the retina.
  - Refer to hand drawn figure of eye
- Each PR cell contains thousands of rhodopsin molecules.
- Possible reason why rhodopsin is most common could be that specific aspects of opsin proteins are useful for sensory reception.

Ch. 1.3b Sensing Light w/o Eyes

- Many organisms lacking eyes can sense light including prokaryotes, plants, algae, and invertebrates.
  - Ex. C. Reindartii has PR within its eyespot that allows the cell to sense light direction & intensity.
    - With flagella, cells can respond to light by swimming toward/away from the light source; process is called *phototaxis. (Positive Phototaxis-* toward light*, Negative-* away*)*
    - Thus allowing the cell to reach optimum light and maximize light capture for photosynthesis.
    - Light absorption by the eyespot is linked to the swimming response by a signal transduction pathway where light absorption triggers rapid changes in potassium and calcium ion conc generating a cascade of electrical events that change the beating pattern of the flagella used for locomotion

- A **Phytochrome** is a PR found in plants that senses light & is critical for photomorphogenesis (process when seedlings are exposed to light.
    - Found in cytosol and initiates a signal transduction pathway when exposed to red light, thus activating hundreds of genes that code for proteins in photosynthesis.

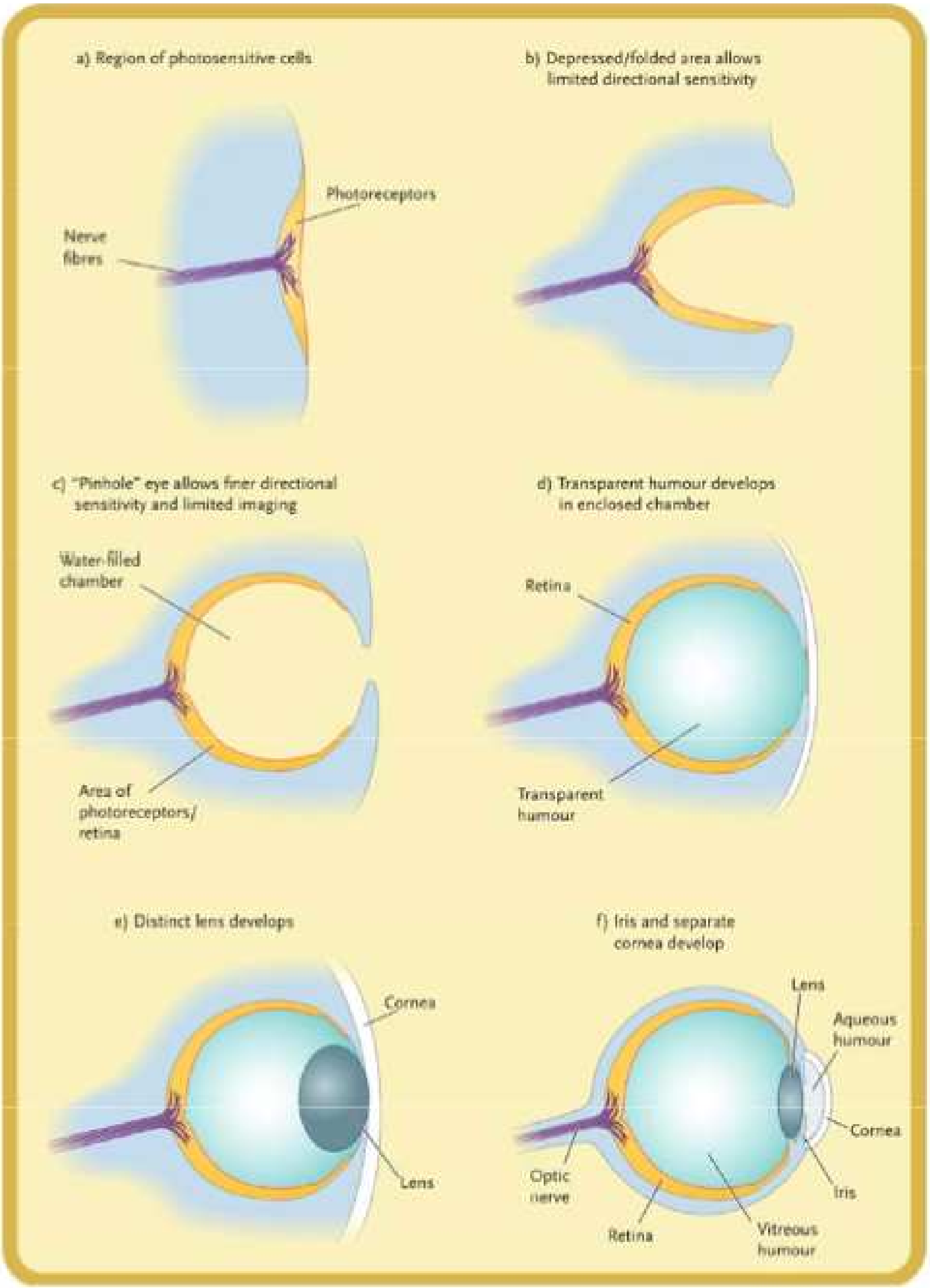
Ch. 1.3c The Eye

- The eye can be defined as the organ animals use to sense light
- Vision requires a brain/simple nervous system to interpret signals sent from the eye.
- Simplest eye is the **ocellus** found in planarians.
    - Enables sensing of light direction & intensity
- Advances in vision are derived from "image forming eyes" that are found as either compound eyes or single lens eyes.
    - Compound eyes are common in insects & contain thousands of tightly packed ommatidia (eyes)
        - Light enters the ommatidia and focuses onto a bundle of PR cells that send signals to the brain which receives an image of the world.
        - Adept at detecting motion
    - In **single-lens eyes**, light enters the transparent cornea, a lens concentrates the light, and a layer of PR cells at the back of the eye, the retina records the image.

1.3d Darwin & the Evolution of the Eye

- Darwin proposed that the eye did not suddenly appear, it evolved by mutation & natural selection over time from a simple eye.

- Takes approx. 500 mill years for an eye from a patch of light sensitive cells to evolve.
- Optically refined eye must evolve at the rate of the brain to allow advanced neural processing from the optic nerve.
- *Refer to evolution of eye on p.10 figure*
    - *Eye Cup*- senses light, can see shadows, slightly focused
    - *Pinhole eye*- cup is more severe, permits light to be focused on PR allows rough images of shapes to be seen.
    - *Primitive Lens*- protects PR, focuses light even further for a better image.


a) Region of photosensitive cells
Photoreceptors
Nerve fibres
b) Depressed/folded area allows limited directional sensitivity
c) "Pinhole" eye allows finer directional sensitivity and limited imaging
Water-filled chamber
Area of photoreceptors/ retina
d) Transparent humour develops in enclosed chamber
Retina
Transparent humour
e) Distinct lens develops
Cornea
Lens
f) Iris and separate cornea develop
Lens
Aqueous humour
Cornea
Iris
Optic nerve
Retina
Vitreous humour

    - *All forms of eye still exist in different animals, BEST EYE IS THE EYE THAT WORKS FOR THAT ORGANISM. (ex. Brain of planaria cannot handle camera eye)*
- In order to see color, specialty PR are needed to pick up specific wavelengths

1.4 Light Can Damage Biological Molecules

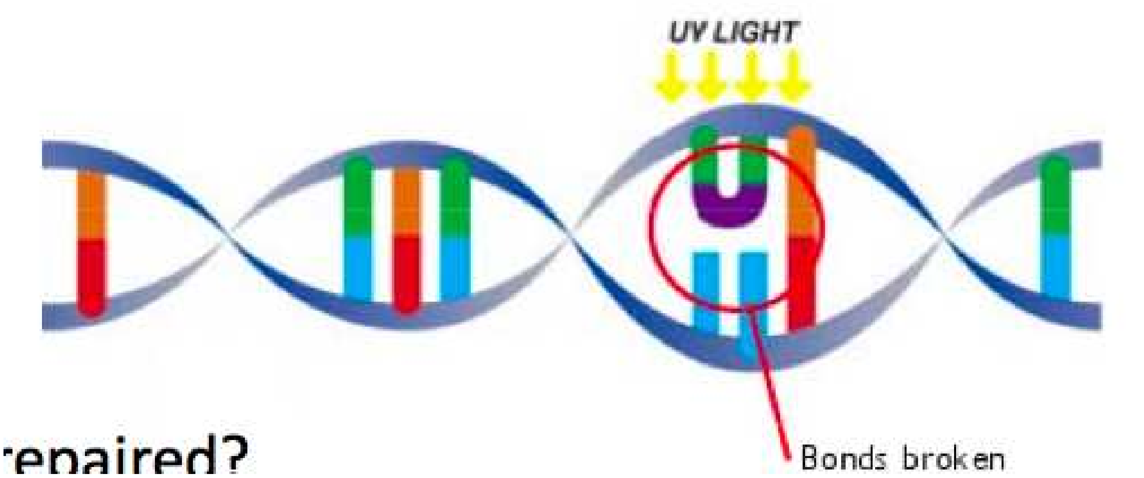
- George Wald reasoned that light is used by organisms b/c it's the most dominant form of EM radiation reaching Earth.
    - Shorter wavelengths of EM radiation are absorbed by the ozone layer, while longer are absorbed by H_2O (g) & CO_2.
    - Shorter wavelengths also destroy chemical bonds holding living molecules together
        - Wouldn't only excite electrons in a pigment; rather oxidize the molecule producing ions. (Ionizing radiation= short EM waves)
    - Longer wavelengths do not supply enough E to electrons for photochemistry
        - Readily absorbed into water found in all living things

1.4a Damage by Light: Direct Effects

- All organisms exposed to sunlight have developed mechanisms either to help prevent or repair light-induced damage
- The photosynthetic apparatus is comprised of pigment- protein complexes that trap E & convert it to CE.
    - These protein components are damaged by this high E environment
        - During evolution, rapid repair of photosystems developed early to maintain photosynthesis.
        - All photosynthetic organisms have **carotenoids**, pigments that protect the photosynthetic apparatus from high light levels by absorbing excess light & safely dissipating the E as heat.

1.4c Damage by Light: Indirect Effects

- Light from sun is harmful b/c of accompanied UV radiation.
- EM radiation b.w blue light & x rays; 200-400 nm
- Earth is protected by the ozone layer from UV-C but not from longer UV-B & UV-A
- B/c of high E, UV radiation randomly ionizes atoms in pigment molecules, proteins, and DNA
- UV light interacts with nucleotide bases & forms a dimer when neighboring bases covalently bond together
    - This changes the shape of the double helix, prevents replication and hinders gene expression.
    - Despite repair mechanisms, excessive amounts of dimers can result in mutations or cancer
    - Dimers occur naturally, but we have a repair system in place



- Most organisms cannot escape UV light and therefore protect themselves (fur, feathers)
- Melanin is a pigment that absorbs UV radiation and is synthesized from the human skin cells melanocytes.
    - Prevents UV radiation from penetrating skin & destroying essential B vitamin folate.

    - Excessive exposure to the sun results in higher levels of melanin as they require more protection from the sun.
    - Higher levels of melanin coincide with skin color over a large period of time.
    - Melinogenesis is the process of making more melanin in respose to body requirements (ex. Sun burning)
- UV radiation is required to synthesize vitamin D (critical for bone development, Vitamin D is required to absorb calcium)
    - High melanin levels lead to vitamin D deficiency common in darker skinned people who live in areas with minimal amount of sun exposure.
- **Rickets:** occurs when calcium is not absorbed into the skeletal system results in brittle bones that cannot sustain pregnancy.

1.5 Role of Light in Ecology & Behavior

- Organisms are adapted to specific light environments from total darkness to light
- Physiological & behavioral responses are geared to daily changes in light & darkness & are called circadian rhythms
    - Circadian rhythms are found in all forms of life & evolved to enable organisms to anticipate changes in the light environment
        - Controlled by an internal organism-based clock found in the suprachiasmatic nucleus (SCN) , a region in the hypothalamus
        - The SCN receives light inputs via the optic nerve to set the clock that regulates bodily function including the appropriate time to DNA replicate or secrete melatonin.
- Organisms use color to attract, warn, or camouflage
    - Plants exhibit various colorful characteristics in order to attract potential pollinators that differ in perception of light.
    - Many specialized relationships b.w plants and their pollinators

        - **Coevolution:** simultaneous evolution of adaptations in two or more populations that interact so closely that each is a strong selective force on the other
- Aquatic habitats have altered light environments b/c water weakens and scatters red long wavelengths.
    - Below 30 m only monochromatic blue, 150m is a total absence of light
- Phytoerythrin is an accessory photosynthetic pigment that only absorbs blue light, giving red algae its color. r
- Artificial lighting disrupts biological processes like bird migration & orientation of nocturnal animals
- Impact of light penetration on ocean characterics & organisms that live there:
    - Fish in the dark are dull, colourful in the light
    - Plants have decreased light forcing the plant to photosynthesize at a slower rate, and more effectively.

1.6 Life in the Dark

- Many nocturnal animals (moths, fish, bats, frogs) see very well under dim light conditions
- Various animals including the blind mole rat are functionally blind but descended from ancestors with functional eyes.

1.7 Organisms Making Their Own Light: Bioluminescence

- **Bioluminescence** is the ability of an organism to use CE to make light
    - CE in the form of ATP excites an electron in a substrate molecule to a higher excited state, and when the electron returns to ground state, the E is released as a photon of light.
    - This light is used to attract prey, mates, communicate or hide.

1.8 Ecological Light Pollution

- Reduces the amount of visible stars in the sky
- Collision hazards for birds, bats, animals, etc