Solution Manual for CDN ED Biology Exploring the Diversity of Life 2nd Edition by Russell Peter Hert ISBN 0176503757 9780176503758

1 Light and Life

IF NOTHING ELSE, MY STUDENTS SHOULD LEARN…

1. Light drives and/or affects many biological processes, directly or indirectly.
2. Light serves as an important source of energy, but can also be used by organisms to gather information about their surroundings.

LEARNING OBJECTIVES

Students should be able to:

Define key terms (nature of light): light, photon, wavelength, electromagnetic spectrum, photosynthesis, chloroplast, pigment, conjugated system, chlorophyll, proton pump. [*Knowledge*]

Explain how the structure of a pigment relates to what is observed when light is absorbed. [*Comprehension*]

Describe the potential fates of a photon when it encounters matter, and explain how one of the possible fates has key biological significance. [*Comprehension*]

Describe, in general terms, how the products of photosynthesis sustain most organisms on Earth. [*Comprehension*]

Define key terms (light as information source): photoreceptor (rhodopsin, phytochromes as examples), opsin, retina, photoreceptor, eye, eyespot, compound eye, ommatidia, camera eye. [*Knowledge*]

Describe how organisms can sense light without image forming eyes. [*Comprehension*]

Explain how the ability to sense light could provide an advantage to an organism, if this ability exceeded that of other competing organisms. [*Comprehension*, *Analysis*]

Describe, in general terms, the evolution of image forming eyes from early simple regions of photoreceptor cells. [*Comprehension*]

Define key terms (light damage): photosystem, ultraviolet radiation, thymine dimer, absorption spectrum, melanin, vitamin D. [*Knowledge*]

Provide examples of how light can damage biological molecules, in particular, information molecules (i.e., RNA and DNA), directly and indirectly. [*Comprehension*]

Describe the potential impact of DNA damage. [*Comprehension*]

Compare and contrast the benefits and disadvantages of melanin production in human skin. [*Analysis*]

Explain how light is involved in the synthesis of Vitamin D in humans. [*Comprehension*]

Define key terms (light in ecology/behaviour): circadian rhythms, biological clock, melatonin, photoperiod, diurnal, camouflage, pollination, phytoerythrin, light pollution, natural selection. [*Knowledge*]

Provide an example of how daylight (or length of day) can affect physiology or behaviour of plants/animals. [*Comprehension*]

List and describe the components of the current model of circadian timekeeping. [*Knowledge, Comprehension*]

List and briefly describe the different parts of the brain and signals involved in human circadian timekeeping. [*Knowledge, Comprehension*]

Describe circadian rhythms and their uses, contrasting the systems in plants and humans. [*Comprehension, Analysis*]

Describe the usefulness of colour in nature (e.g., sex selection, mimicry, warning). [*Comprehension*]

Describe different ways that colour influences animal behaviour, providing examples. [*Comprehension*]

Explain the effect of water on light, and how this can influence marine life. [*Comprehension*]

Define key terms (bioluminescence): bioluminescence/bioluminescent, ATP. [*Knowledge*]

List two different types of organisms that can produce bioluminescence.

[*Knowledge*] In basic terms, explain potential uses of bioluminescence.

[*Comprehension*]

Explain why artificial light is problematic for many organisms and can be considered a form of pollution. [*Comprehension*]

WHY IS THIS CHAPTER IMPORTANT TO SCIENTISTS?

As light is so integral to photosynthesis and involved in many biological phenomena (as described in this chapter), an understanding of the nature, properties, and impact of light is vital to many areas of biological research.

Much of evolution has been shaped by selective forces relating to light (as energy source, information source, etc.).

Researchers are looking into ways of harnessing the energy of light, using biological (or biologically derived) molecules in biotechnology, nanotechnology, and cancer treatment.

WHY SHOULD STUDENTS CARE?

Understanding the role of light in various biological phenomena will be helpful throughout the course. It provides a way to link many topics in biology that students might otherwise view as isolated, tying biochemical/biophysical properties and processes to organismal, physiological, and behavioural aspects.

Understanding how sensing light, in even the most basic way, can be useful to an organism can help students to appreciate and understand the gradual nature of evolution of the eye.

Understanding how light can damage biological molecules can provide useful information in understanding how skin cancer arises.

WHAT ARE COMMON STUDENT MISCONCEPTIONS/STUMBLING BLOCKS?

1. The nature of light (wave and particle) can be confusing to students. Depending on the background preparation of your students, and the level of detail you wish them to know, you may want to spend some time discussing this.
2. It is often counterintuitive to students that colour is the result of those wavelengths of light that are NOT absorbed by a pigment. This is important in terms of the nature of pigments, and related to absorption spectra (which will be discussed in Chapter 7, Photosynthesis).
3. There can be some confusion relating to the fact that light is key to photosynthesis and other vital biological processes, yet can damage biological molecules (even leading to development of cancers, in some cases). While this may initially be

counterintuitive to students, this does provide an opportunity to discuss the properties of light that allow it to be so beneficial in many ways, yet cause damage to proteins and DNA.

4. The information in this chapter includes a lot of details and terminology that students will not be familiar with, particularly if this is the first topic in an introductory course. Instructors are encouraged to use layman explanations for those terms they want students to understand, and to provide clear expectations regarding what students need to know vs. what is for interest at this stage.

5. Many people have heard that the evolution of the camera eye is not possible, as an argument for intelligent design. Anti-evolutionists consider the eye to be "irreducibly complex," arguing that the eye is so complex that it could not have evolved in a step-like process (they ask, "What good is half an eye?" to which we respond, "Better than no eye at all!"). This misconception may affect some student attitudes and we recommend that it be addressed (debunked) early, showing known examples of "intermediate" eyes. It can be used as an example of how science is done by looking at evidence, outside the commonly presented "scientific method."

6. We have found that students are often confused by the levels of melanin and vitamin D production from photoconversion reactions in the body. Some students believe that vitamin D increases melanin production. A full understanding of how photons can be absorbed, transmitted, or reflected may help prevent this confusion.

WHAT CAN I DO IN CLASS?

Depending on the time you have allotted to this chapter, and the objectives chosen for student learning, the various aspects of this chapter can be introduced very briefly or explored more deeply. There is an opportunity to introduce themes that will extend across an introductory survey course, and you may want to draw student attention to this explicitly.

Many elements of the chapter could be drawn together using an example organism, such as a bird:

> Energy is required for metabolism from food, which originates from plants, as result of photosynthesis. Bird eyes/vision are worth mentioning (especially considering pollinators—see below; raptors may also be useful examples).
>
> Circadian rhythms, migration (melatonin believed to be involved in determining migratory direction, especially for first migration; see Schneider et al., 1994a; Schneider et al., 1994b), and reproduction (Sherwood et al., 2002) can be linked.
>
> Light pollution effects on birds may be of interest (one visible effect is when birds crash into windows—see Longcore and Rich, 2004). Some researchers believe that lights attracting insects may cause population declines and thus declining

food source for insectivorous birds (or birds whose young are insectivorous); as insects that buzz about lights all night, then fall exhausted to ground, no longer have the energy to feed themselves or to procreate.

Light serves as information, typically as/through colour. Considering intersexual selection in birds, female choice is often on the basis of colour. Colour in birds has been shown to be indicative of health. Dietary changes that made blue-footed boobies more blue also resulted in more robust immune system. Females often select males by virtue of the colour of a structure, in this case, the feet. It is an honest sign as to the strength of the immune system (see Velando et al., 2006).

The "Why It Matters" introduction discusses Monet, and the changes in his painting relating to onset of cataracts. This could be explored, looking at the components of the human eye, and the mechanisms of (or, in the case of cataracts, the problems) perceiving light in the process of sight. There are websites that can simulate vision affected by cataracts (see "Other Resources"), and you may want to show these in class. It may be useful to get students discussing how the physical development of a cataract results in blurry vision, considering the nature of light and how we use light as an information source in sight. (See the "Unanswered Questions" material below for a topic that could be discussed in class.)

The concepts of photon reflection, transmission, and absorption can be explored in class (**demonstration** or **group activity**) or the laboratory using light bulbs, coloured paper, and translucent coloured filters. Prior to the activity or demonstration, students can be asked to predict what will occur when visible light is shone onto each item. [*Stumbling Block 2*]

Prior to discussing vision, you can include a black slide (and turn off the lecture hall lights) to put the room in (temporary) darkness. (Alternatively, ask students to close their eyes.) **Ask** students: What has changed? What is the impact of this change? This leads into the idea of light as a source of information, and the biological mechanisms for sensing and using this information.

In **discussing** the eye, Figure 1.10 shows the *Chlamydomonas* eyespot, while Figures 1.12, 1.13, and 1.14 provide a good representation of eyes of varying complexity. The evolution of the camera eye depicted in Figure 1.15 shows how gradual changes in the ability to detect light (and development of vision) could provide fitness advantages to the organisms. These figures are useful in helping students to understand how the evolution of such a complex structure (the eye) could evolve gradually. Clicker question 2 may be used early in this discussion, and we recommend showing (or asking students to view) the PBS video clip on evolution of the eye (see "Other Resources"). [*Stumbling Block 5*]

In exploring the importance of colour, an instructor can **show additional images** of flowers (as well as Figures 1.27 and 1.28) where petal colours attract particular pollinators. (**Ask**: How do animal pollinators vary? How would a night-flowering plant differ from one that blooms during the day?) An instructor could introduce idea of coevolution, using examples of certain flowering plants and their animal pollinators who have exerted selective forces upon one another, shaping evolution of both organisms. There is considerable concern regarding a decline in bee pollinators, which could have a significant impact on plants, including crop plants; this relates to conservation biology efforts.

Ask students about mimicry with bright colours. This is only useful if deterring predators that can distinguish colours. This relates to bright colours for sexual selection in species that can see colours, and could lead into an introduction to sexual selection.

Students will probably be interested in seeing pictures of animals that lack eyes, and this can lead into a **discussion** about vision and fitness (at a very simple level!).

Introduction of photosynthesis: at this point, the major concept is the transformation of light energy into stored chemical energy. If this is an early chapter in the course, you may want to describe the conditions of life on Earth prior to the appearance of photosynthetic microbes, which leads into topics of subsequent chapters. **Discussion question**: How did early photosynthesis affect the conditions of Earth, and the life we see today? (This leads into concepts covered further in Chapter 2.) Not all photosynthesizers are green (e.g., red and brown algae). This observation can be used to explore different photosynthetic pigments and adaptations to life under water.

Students are likely to find the effects of circadian rhythms in humans highly relevant. You may want to refer students to http://www.hhmi.org/biointeractive/clocks/fall/teenagers.html, which is an easy article for students to read relating to the work of Mary Carskadon (see "Other References" below). This could lead to a **debate** about high school start times.

Ask/discuss: Why do animals have cycles relating to light? Why do plants have circadian rhythms? What similarities/differences exist?

The text shows, and briefly mentions the Mexican blind cavefish (Figure 1.34). **Ask** students: How could it be possible to have circadian rhythms in organisms that lack eyes and are not exposed to light? (Recent research by Cavallari et al., 2011, has indicated that another species of cavefish possesses a food-entrainable biological clock that is not regulated by light.)

Even early in the course, one can introduce model organisms, as they will likely be mentioned frequently. Why do scientists use a fungus (*Neurospora*) to study circadian rhythms? How can we use information about fungal biology to help understand biology in other organisms? This could be an opportunity to have students consult the Purple Pages.

The topic of damage by light provides an opportunity to discuss cancer, which is a complex set of diseases and will appear in many other chapters (e.g., cell signalling, cell cycle, genetics, gene regulation). **Ask** students to consider the characteristics of light that are beneficial to life (which forms?) and aspects that can be detrimental. **Discuss** pigments in role of photosynthesis (e.g., chlorophylls), vs. protection (e.g., melanin, carotenoids). We have found that our students are often very interested in melanin (skin colour). [*Stumbling Block 3*] The role of melanin as a photoprotectant, as well as its biosynthesis, can be an engaging topic. In most introductory courses, the pathways would be too advanced for students to know in detail, but the tyrosine precursor can be shown as an example of an important **amino acid** (it is a precursor for several important biological molecules), tyrosinase as an example of a biosynthetic **enzyme**, melanocytes as specialized skin **cells** (highlight the "cyt," which appears in cell-related terms), and melanosomes as **organelles** within these cells. In discussing later topics, an instructor can revisit melanogenesis as a multi-layered example.

Differences in pigmentation and ability to synthesize vitamin D via photoconversion can be discussed, asking about what occurs populations in regions where less exposure to sunlight occurs than in regions closer to the equator, and how diet can supply Vitamin D in such countries. This topic can even be linked into discussion of water to land transition of plants and animals—development of the ozone layer (Chapter 3) provided protection against radiation, enabling colonization of upper layers of water and land (ecological opportunity). [*Stumbling Block 6*]

See the http://www.lightpollution.org.uk/ website below for links to news stories and arguments that can be used in **discussions/debates** regarding light pollution. (Major question to be posed: "Is light pollution killing our birds?") See Navara and Nelson (2007) for a good discussion of the "dark side of light."

Images of bioluminescent organisms (in addition to Figure 1.36) can be shown to illustrate this phenomenon, which occurs in all sorts of organisms, from tiny bacteria to octopi.

We have found that students visibly enjoyed the camouflage pictures we showed when we were going through this chapter. We have been **starting each class** with a new picture showing camouflage/mimicry. (For ideas, see *National Geographic*'s photo gallery "The Art of Deception": http://ngm.nationalgeographic.com/2009/08/mimicry/ziegler-photography)

Clicker questions:

1. What colour could a photosynthesizing organism be?

   A. green
   B. red
   C. brown
   D. purple
   E. Any of the above colours. *
   F. Only two of the colours in A–D.

This question can be used in discussion of photosynthesis in different types of organisms (e.g., bacteria, archaeans, algae, plants) and the different types of pigments that are present in the different photosynthesizers. There are brown and red algae, and purple photosynthetic bacteria. [*Stumbling Block 2*]

2. The vertebrate eye

   A. is very similar in structure and function to the eye of certain molluscs (squids and octopi). *
   B. could not have evolved from an ancestral patch of photosensitive cells (similar to eyespots possessed by certain single-celled protists and flatworms).
   C. could not be made more effective or efficient.
   D. is an example of an image-forming eye, which is the only type of "eye" that could provide a selective advantage to an organism.
   E. None of the above is true.

This question relates to the common misconceptions about the so-called “irreducible complexity” of the vertebrate eye. [*Stumbling Block 5*] There is considerable evidence of intermediate eye steps in evolution, and that even small improvements in a photoreceptive sensory structure (and corresponding neural developments) could provide significant selective advantages to the possessors of such structures. The vertebrate eye also exhibits some characteristics that probably would have been avoided if it had been designed as a perfect structure (e.g., placement of optical nerve, blood vessels).

UNANSWERED QUESTIONS

Is there any hope for the development of a “bionic eye”?

For most of us, having good vision throughout our lives is something we take for granted. However, a number of diseases result in diminished vision and often progressively lead to blindness. These include retinitis pigmentosa and age-related macular degeneration.

Both age-related macular degeneration and retinitis pigmentosa lead to a loss of vision because they both result in degeneration of the photoreceptor cells (rods and cones) found in the retina at the back of the eye. The rods and cones convert light into electrical impulses, which are carried by the optic nerve to the brain, where images are formed.

For years, the development of an artificial “bionic eye” that could restore at least some vision to people who are otherwise blind has been the realm of science fiction—an unattainable dream for both scientists and those with vision degeneration. However, a great deal of research has been carried out in recent years, specifically in the development of an artificial retina, since this is part of the optic system that is damaged in many forms of vision degeneration. The most significant advances have come with the production of a functional artificial retina through research carried out by Mark Humayun, professor of ophthalmology and biomedical engineering, and his associates at the Doheny Eye Institute at the University of Southern California.

Current versions of the artificial retina, which has been successfully implanted in a number of patients, consist of a flexible, wafer-thin, square grid of 16 electrodes surgically attached in the back of the eye. The system also consists of a miniature camera mounted on a pair of sunglasses. The retina and camera are interfaced by a small external wallet-size computer that converts the information from the camera into electrical signals, which are then sent wirelessly to the artificial retina. From there, the current passes through the optic nerve into the brain. The implant has allowed patients to regain some rudimentary vision, including the ability to detect motion and to distinguish between dark and light.

Given the tremendous technological and engineering hurdles that have been overcome to develop this artificial retina, the results for vision may seem relatively primitive. These problems reflect the highly impressive ability of the vision system to process information. Human vision is remarkably sensitive to a wide range of wavelengths and light intensities and can differentiate subtleties in colour, shading, and depth. There are roughly 1.2 million fibres in the optic nerve, each connected to a neuron which can fire 200 pulses per second.

A single eye can send the brain up to 200 million bits of information per second. Although the current technology does not come close to the staggeringly fast rate of information transfer, the current system is rapidly improving. Advancements include reducing the size and power demands on the camera such that it can be placed within the eye itself. Researchers have also successfully moved from implanting a 16-electrode retina to a more advanced 60-electrode device. Researchers are currently developing a 1000-electrode implant that should allow recipients of the retina to gain facial recognition capabilities.

WHAT OTHER RESOURCES ARE AVAILABLE?

About.com Vision (Cataract vision simulated image): http://vision.about.com/od/eyediseases/ig/Eye-Disease-Simulations/Cataract.htm

Low vision simulation (requires plugin): http://www.webaim.org/simulations/lowvision-sim.htm

A useful article discussing some of the stumbling blocks regarding evolution of complex structures, such as the image-forming eye: Petto, A.J., and Mead, L.S. 2008. Misconceptions about the evolution of complexity. *Evolution: Education and Outreach* 1(4): 505–508.

PBS Evolution of the Eye: includes an excellent short video that demonstrates incremental developments toward the camera eye: http://www.pbs.org/wgbh/evolution/library/01/1/l_011_01.html

HHMI. Seasonal Rhythms: http://www.hhmi.org/biointeractive/clocks/seasons.html

HHMI. Seasonal Rhythms—Sleepy teens: http://www.hhmi.org/biointeractive/clocks/fall/teenagers.html

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Cavallari, N., Frigato, E., Vallone, D., Fröhlich, N., Lopez-Olmeda, J.F., Foà, A., Berti, R., Sánchez-Vázquez, F.J., Bertolucci, C., Foulkes, N.S. 2011. A blind circadian clock in cavefish reveals that opsins mediate peripheral clock photoreception. *PLoS Biology* 9(9): e1001142 DOI: 10.1371/journal.pbio.1001142.

We recommend obtaining permission to show portions of the David Attenborough BBC *Private Life of Plants* video—there are many beautiful clips of pollinators and flowers, adaptations that illustrate coevolution.

Rodríguez-Gironés, M.A., and Santamaría, L. 2004. Why are so many bird flowers red? *PLoS Biology* 2(10): e350 doi:10.1371/journal.pbio.0020350.

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Tarlow, E.M., Hau, M., Anderson, D.J., and Wikelski, M. 2003. Diel changes in plasma melatonin and corticosterone concentrations in tropical Nazca boobies (*Sula granti)* in relation to moon phase and age. *General and Comparative Endocrinology* 133(3): 297–304.

Navara, K.J., and Nelson, R.J. 2007. The dark side of light at night: physiological, epidemiological, and ecological consequences. *Journal of Pineal Research* 43(3): 215–224.

Longcore, T., and Rich, C. 2004. Ecological light pollution. *Frontiers in Ecology and the Environment* 2(4): 191–198.

LightPollution.org.uk: http://www.lightpollution.org.uk/index.php?pageId=0

Ecology of the Night (Muskoka Heritage Foundation): http://www.muskokaheritage.org/programs/dark-skies/ecology-of-the-night/

Velando, A., et al. 2006. Pigment-based skin colour in the blue-footed booby: an honest signal of current condition used by females to adjust reproductive investment. *Oecologia* 149(3): 535–542.

National Geographic photo gallery, “The Art of Deception”: http://ngm.nationalgeographic.com/2009/08/mimicry/ziegler-photography)

Astrobiology Magazine. Living in the dark: http://astrobio.net/exclusive/207/living-in-the-dark