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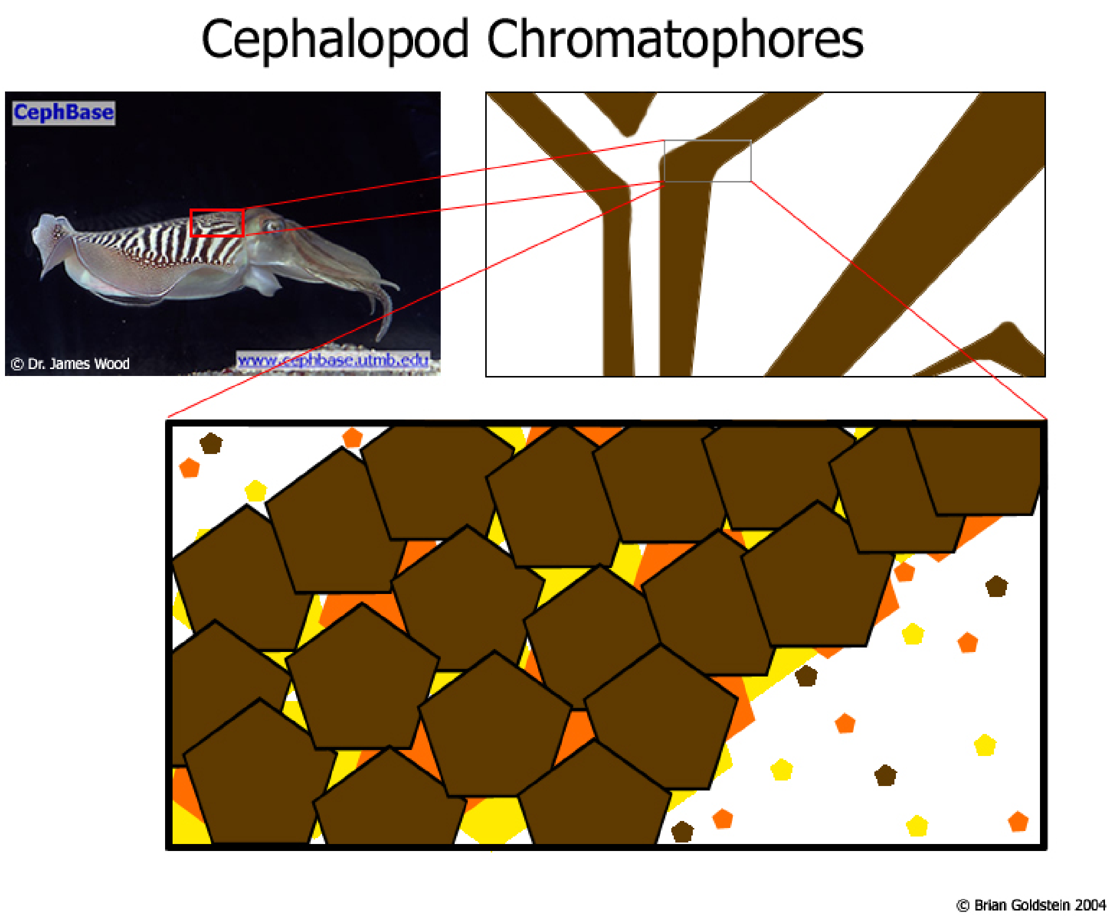
How Cephalopods Change Color

By Dr. James Wood and Kelsie Jackson

Introduction

Cephalopods have often been referred to as the chameleons of the sea. However, members of the cephalopod family (with the exception of the nautilus) have an ability to change color that is even more impressive than that of the chameleon. Unlike the chameleon many of the cephalopod's color producing cells are controlled neurally which allows them to change colors at an alarming rate (Hanlon and Messenger 1996). This web resource explains the mechanisms that allow cephalopods to change colors, an ability that has evolved through adaptation and natural selection over time. Evolution, natural selection and adaptation are important concepts in the study of life science and the ability of the cephalopod to change color is an excellent example of these.

The patterns and colors seen in cephalopods are produced by different layers of cells stacked together, and it is the combination of certain cells operating at once that allows cephalopods to possess such a large array of patterns and colors.



(Figure 1)

The most well known of these cells is the chromatophore. Chromatophores are groups of cells that include an elastic saccule that holds a pigment, as well as 15-25 muscles attached to this saccule (Hanlon and Messenger 1996). These cells are located directly under the skin of cephalopods. When the muscles contract, they stretch the saccule allowing the pigment inside to cover a larger surface area. When the muscles relax, the saccule shrinks and hides the pigment. Unlike other animals, the chromatophores in cephalopods are neurally controlled, with each chromatophore being attached to a nerve ending (Messenger 2001). In some squid, each chromatophor muscle is innervated by 2 to 6 nerves that directly link to the animals brain (Messenger et al 2001).

In this way the animal can increase the size of one saccule while decreasing the size of another one right next to it. This allows the cephalopods to produce complex patterns (Messenger 2001, Messenger et al 2001), such as the zebra stripes seen in aggressive displays by male cuttlefish. The speed at which this can be controlled allows the animal to manipulate these patterns in a way that makes them appear to move across the body. In some species of cuttlefish, it has been noted that while hunting, the cuttlefish may produce a series of stripes that move down their bodies and arms. Some scientists have suggested that this could be used to mesmerize prey before striking, but the purpose of this behavior has yet to be proven. The pigments in chromatophores can be black, brown, red, orange or yellow. They are not responsible for producing the blue and green colors seen in some species. Interestingly, many deep water forms possess fewer chromatophores as they are less useful in an environment in little or no light.

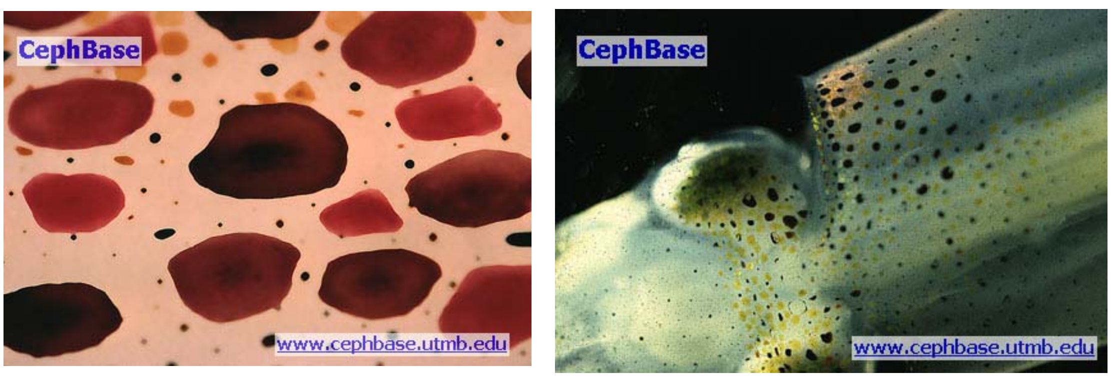


Figure 2. A) Chromatophores on skin of Loligo. (CephBase image No. 280 by Roger T. Hanlon) B) Chromatophores visible on Lolliguncula brevis (CephBase image No. 263 from UTMB).

Iridophores are found in the next layer under the chromatopphores (Hanlon et al 1990, Cooper et al 1990). Iridophores are layered stacks of platelets that are chitinous in some species and protein based in others. They are responsible for producing the metallic looking greens, blues and golds seen in some species, as well as the silver color around the eyes and ink sac of others (Hanlon and Messenger 1996). Iridophores work by reflecting light and can be used to conceal organs, as is often the case with the silver coloration around the eyes and ink sacs. Additonally they assist in concealment and communication. Previously, it was thought that these colors were permanent and unchanging unlike the colors produced by chromatophores. New studies on some species of squid suggest that the colors may change in response to changing levels of certain hormones (Hanlon et al 1990, Cooper et al 1990). However, these changes are obviously slower than neurally controlled chromatophore changes. Iridophores can be found in cuttlefish, some squid and some species of octopus.

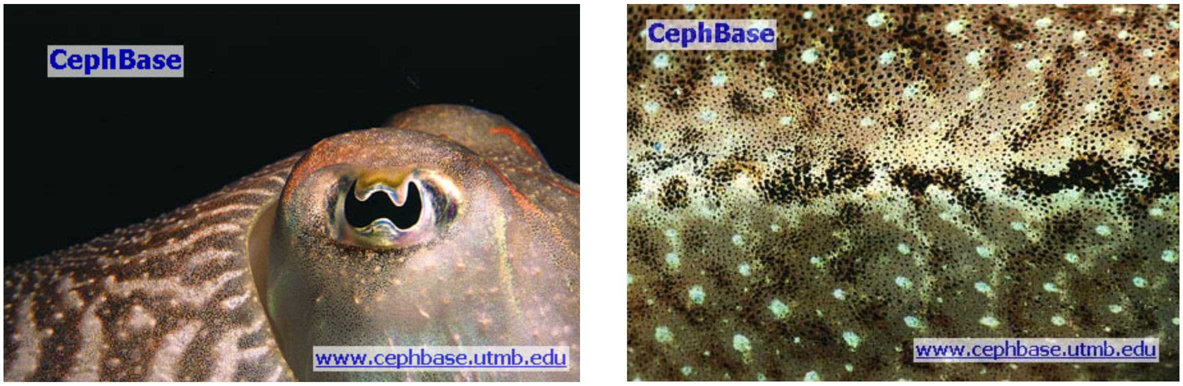


Figure 3. A) Iridophores and chromatophores on skin of Sepioteuthis sepioidea (CephBase image No. 287 by Roger T. Hanlon) . B) Red and green iridophores visible on head of cuttlefish, sepia officinalis (CephBase image No. 1378 by James B. Wood).

Leucophores are the last layer of cells (Hanlon and Messneger 1996). These cells are responsible for the white spots occurring on some species of cuttlefish, squid and octopus. Leucophores are flattened, branched cells that are thought to scatter and reflect incoming light. In this way, the color of the leucophores will reflect the predominant wavelength of light in the environment. In white light they will be white, while in blue light they will be blue. It is thought that this adds to the animal's ability to blend into its environment.

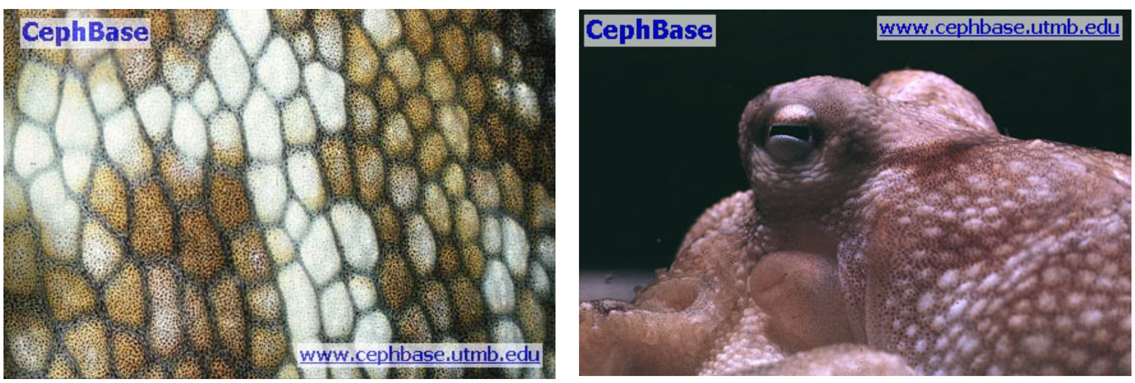


Figure 4. A) Leucophores (white areas) visible on skin of Octopus burryi (CephBase image No. 294 by Roger T. Hanlon). B) Octopus burryi showing white spots due to leucophores (CephBase image No. 42 by Martin A. Wolterding).

Cephalopod's have one final ability to change color and pattern, the photophores. These produce light by bioluminescence (for more information see "How Light Effects Marine Organisms" in "Light, Color and Cephalopods"). Photophores are found in most midwater, and deep sea cephalopods and are often absent in shallow water species. Bioluminescence is produced by a chemical reaction similar to that of a chemical light stick. Photophores may produce light constantly or flash light intermittently. The mechanism for this is not yet known, but one theory is that the photophores can be covered up by pigments in the chromatophores when the animal does not wish for them to show. Some species also have sacs containing resident bacteria that produce bioluminescence such as the tiny squid Euprymna. Mid water squid use photophores to match downwheling light or to attract prey (Young and Roper 1977, Johnsen et al 1999).

Figure 5. Histioteuthis sp. (CephBase image No. 577 unknown photographer) with numerous photophores.

It is the use of these cells in combination that allow cephalopods to produce amazing colors and patterns not seen in any other family of animal. However, not all species of cephalopod possess all the cells described above. For instance, photophores may be necessary for animals in deep water environments but are often absent in shallow water forms. Deep sea species may possess few or even no chromatophores as their color changes would not be visible in an environment with no light. Recent research has suggested that there may be some correlation between the amount of chromatophores (and hence the complexity of patterns available) and the type and complexity of a cephalopod's environment. For instance, midwater species may possess fewer chromatophores. While species living in reef type environments may possess more. However, further research still needs to be conducted in this area.

To find out why cephalopods possess this ability and how they use it to their advantage visit the "Why Cephalopods Change Color" page.

How Cephalopods Change Color-Teacher Resource

By Dr. James Wood and Kelsie Jackson

Abstract

"How Cephalopods Change Color" teaches students about the mechanisms behind the cephalopod's amazing abilities to camouflage and display using colors and patterns. Students learn about the different types of cells used in color change including chromatophores, leucophores, iridophores and photophores. The make up of the different types of cells are discussed as well as how these cells function to produce the vivid displays seen in some species and the ability to camouflage almost perfectly to their environment in others. Students will also learn how these cells are used singly as well as in combination with other cells to the cephalopod's advantage. Cephalopod color change is linked to concepts such as evolution, adaptation and natural selection which are important life science topics for students to grasp.

Objectives

- To investigate the mechanisms behind cephalopod color change.
- To examine the make up of different color and light producing cells and how these are used in combination with one another to produce color change.
- To investigate how different types of cells are used to make cephalopods more competitive in their environments.

Introduction

Cephalopods are well known for their awesome abilities to change color to either seemingly disappear into their environments or to produce stunning displays. This ability is due to a combination of different color and light producing cells including chromatophores, leucophores, iridophores and photophores. Each of these cells is responsible for a different aspect of cephalopod color change. Depending on the cephalopod and its environment, it may use all or only some of these cells in its daily life.

Chromatophores

Chromatophores are the main color changing cells in octopus, squid and cuttlefish. The chromatophore is made up of a saccule containing pigment as well as 15-25 muscles. When the muscles are contracted, the saccule expands making more of the pigment visible. As each chromatophore is neurally controlled, with each individual chromatophore being attached to a nerve ending, the cephalopod can increase or decrease the amount of visible pigment at an astounding rate. Additionally, it is able to change the amount of exposed pigment in individual chromatophores to produce patterns. The chromatophores are located just under the skin and can contain black, brown, red, orange or yellow pigments. Deep water cephalopods may often have few if any chromatophores as color change is not as useful in environments with little or no light.

Iridophores

Iridophores are found in a layer under the chromatophores. They are responsible for producing the metallic looking greens, blues and gold colors seen in some species as well the silver coloration sometimes seen around the eyes and ink sac. These cells are not neutrally controlled and it was recently thought that their colors were permanent. However, new research suggests iridophores may be controlled by hormones, although this means any change is much slower than that of chromatophores--similar to the speed of color change in chameleons. Chromatophores can also be used to cover iridophores when needed.

Leucophores

Leucophores are responsible for the distinct white spots seen in some species. These cells scatter and reflect incoming light. However, they will reflect and scatter the predominant wavelength of incoming light so the cells may change color depending on what the predominant wavelengths are. For instance, near the surface where there is still an abundance of white light, the cells will be white. Whereas in deeper water, where blue light is more abundant, they will reflect this.

Photophores

Photophores are light producing cells that are responsible for bioluminescence. A chemical reaction occurs in these cells similar to that of a chemical light stick to produce light. Some species also have sacs containing luminescent bacteria for the same purpose. Often these organs can also be covered by chromatophores to hide their light.

Often these cells are used in combination. For example, in camouflage, the chromatophores will be used to match the background color, iridophores will reflect ligh, to disguise visible organs, and leucophores may be used to break up the body pattern. Photophores can be used to either stand out or to blend in. It has been shown in some species of squid that photophores can be used to match down welling light and make the animal harder to detect in midwater when viewed from below. There is evidence to suggest that the amount and type of color producing cells in a species may be related to the type and complexity of its environment. However, research is still being conducted in this area. Obvious differences can be seen between deep and shallow water species in regard to the number and use of chromatophores. This is to be expected given the differences in available light. As well as other things, color changes in cephalopods are used as a primary defense mechanism by assisting with camouflage. This allows the animals to remain competitive without the protection of hard shell employed by their mollusk relatives.

Key Concepts

- Color change and patterning is due to the combination of different types of cells acting together.
- Chromatophores produce the black, brown, red, orange and yellow colors.
- Chromatophores are neurally controlled which allows for almost instant color change.
- Iridophores reflect light to produce the greens, blues, gold, and silvers seen in some species.
- Leucophores reflect the predominant wavelength of light in the environment and are often responsible for the white spots seen in some species.
- Photophores are light organs that produce bioluminescence.
- Different cephalopods in different environments use different combinations of cells to produce color change.

Student Learning Objectives

- To investigate the mechanisms behind cephalopod color change.
- To learn about the different types of cells involved in color change.
- To examine how these cells work in combination with each other to produce color change.
- To understand how the combination of cells used in color change differs between environments.

Conclusion

After investigating cephalopod color change by using the page "How Cephalopods Change Color" followed by in class discussion, students will have a solid understanding of how color change occurs in cephalopods. They will be able to identify the different types of cells responsible for color change and have a basic understanding of how these cells work to produce color and/or light. They will also understand that different species of cephalopods may possess and use different combinations of color producing cells depending on their environment. More importantly, this resource will give students an in-depth example of adaptation, natural selection and evolution of a species, which are important concepts in the study of life science.

Web Resources and Bibliography

- An excellent article by Alison King describing how cephalopods change color

http://is.dal.ca/~ceph/TCP/chroma1.html

- Browse the image database in CephBase using keywords: light, color, chromatophore, etc.

http://www.cephbase.utmb.edu/

- Diagram of a chromatophore

http://tolweb.org/accessory/Cephalopod_Chromatophore?acc_id=2038

- Tutorial about color change in squid with images of chromatophores

http://hermes.mbl.edu/publications/Loligo/squid/skin.0.html

- Scientific journal article about the use of iridophores in squid (advanced)

http://www.vthrc.uq.edu.au:16080/ecovis/StaffPostgrads/images/MathgerDenton.pdf

- Article on cuttlefish coloration

http://www.findarticles.com/cf_dls/m1134/3_109/61524425/p2/article.jhtml?term=

- More on cuttlefish color changes

http://www.windspeed.net.au/~jenny/cuttlefish/camouflage.html

- Also see section on sense organs in

Hanlon, R.T. & Messenger, J.B. (2003) *Cephalopod Behaviour*, Cambridge University Press, Cambridge UK.

- Further reading for advanced students-downloadable from CephBase

Messenger J.B. (2001) Cephalopod chromatophores: neurobiology and natural history. *Biology Review.* 76 : pp. 473-528

Also:

Messenger J.B., Cornwell C.J. and C.M. Reed 1997. L-glutamate and serotonin are endogenous in squid chromatophore nerves. Journal of Experimental Biology. Company of Biologists Ltd, Cambridge. 200 (23) : pp.3043-3054

Cooper K.M., Hanlon R.T. and B.U. Budelmann 1990. Physiological color change in squid iridophores II. Ultrastructural mechanisms in Lolliguncula brevis. Cell and Tissue Research. 259 : pp.15-24

Hanlon R.T., Cooper K.M., Budelmann B.U. and T.C. Pappas 1990. Physiological color change in squid iridophores I. Behavior, morphology and pharmacology in Lolliguncula brevis. Cell and Tissue Research. 259 : pp.3-14

Young R.E. and C.F.E. Roper 1977. Intensity regulation of bioluminescence during countershading in living midwater animals. . Fishery Bulletin. 75 (2) : pp.239-252

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Johnsen S., Balser E.J., Fisher E.C. and E.A. Widder 1999. Bioluminescence in the deep-sea cirrate octopod Stauroteuthis syrtensis Verrill. Biological Bulletin. 197 (1) : pp.26-39

Vocabulary

Bioluminescence: The production of light by way of a chemical reaction that occurs in the photophores. In some species bioluminescence is produced by luminescent bacteria contained in sacs in the body.

Chromatophore: A color producing organ made up of a saccule containing pigments and radial muscles. When expanded the chormatophore looks like a polygon of a certain color. The amount of color on the animal's skin changes as the muscles radiating from the saccule expand and contract. See the figure on chromatophores in this section for a graphic. Chromatophores are found in many octopus, squid and cuttlefish but also in some other animals.

Iridophore: Reflecting cells in the form of layered stacks of platelets which are either chitinous or protein based. Produces the metallic looking blue and green colors seen in some species as well as silver patches around the eyes and ink sacs.

Leucophore: Reflecting cells found in cuttlefish, some squid and some octopus in the lowest pigment layer. Produces spots on the animal by reflecting the most predominant wavelength of light in the environment, i.e. blue light, blue patches. Responsible for the white spots seen in some species

Photophores: Light producing organs, involved in bioluminescence. Place where the light producing chemical reaction occurs.

How Cephalopods Change Color
Frequently Asked Quotations

Question
How can cephalopods change color instantly?

Cephalopods primarily change colors by using chromatophores. Imagine a small clear balloon that is filled with ink. Now imagine five or so small muscles attached to the balloon and radiating away from it. When the muscles are relaxed, the surface area of the sac is small and the color is not expressed. When the muscles contract, the surface area becomes much greater and is seen as color. What I have just described is a chromatophore, and they are responsible for colors such as yellow, orange, brown, red, blue and black depending on the ink. All of this is under the control of their advanced nervous system. Although cephalopods are known for their large brain, they also have a lot of local control, much more than any vertebrate. For example, 2/3 of the nerves in an octopus are in the arms and each sucker segment in the arm has several sets of ganglia. All this local processing of information makes cephalopods **very** fast. Cephalopods also have iridocytes which differentially reflect light. They can change texture and create ink decoys as well.

Question
How big are the color changing cells, *chromatophores,* in cephalopod skin?

Fully expanded chromatophores are up to 1.5mm in diameter in squid and 0.3mm in cuttlefish. I would guess that they are at least 100 times smaller when not expanded. Chromatophore density ranges from 8 to 230mm (squared). Cephalopods, like octopuses, have more and smaller chromatophores that are able to create more complex and detailed patterns - just like a printer with a higher dpi.

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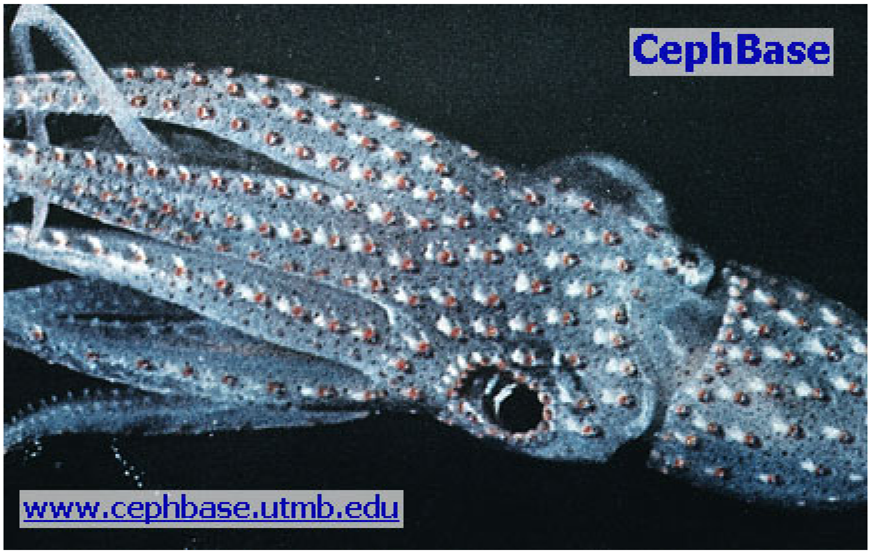
Teachers Information

Materials and Activities

Print out in color the photographic images from the CephBase website (http://www.cephbase.utmb.edu/) listed below with the image number used in the site:

CephBase 283. James B. Wood



CephBase 577, James B. Wood

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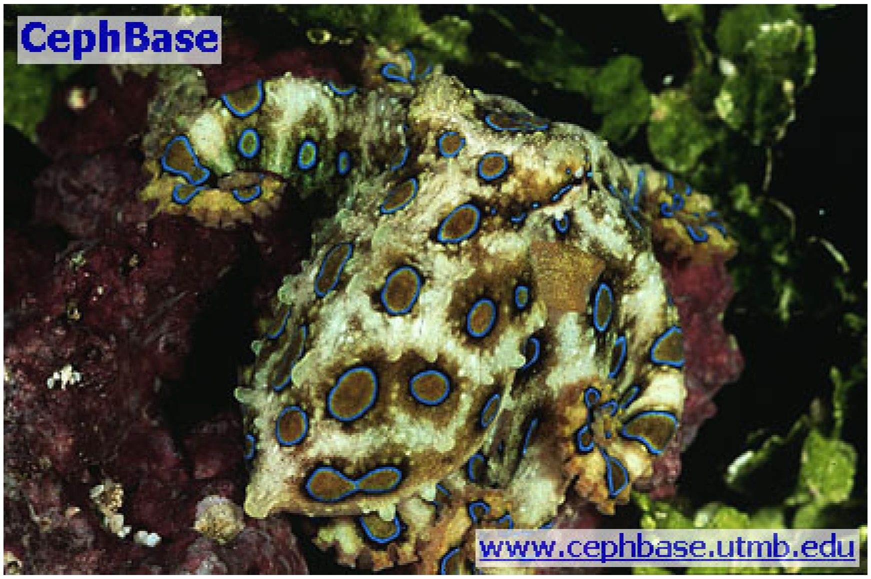

CephBase 620. Roy L. Caldwell

CephBase 761. James B. Wood

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CephBase 1414 James B. Wood

CephBase 1415 James B. Wood

By using the actual photographic image number from the CephBase website, should students want to revisit the images from a computer terminal, they will be able to find the correct image.

Print out copies of the vocabulary (terms) for this module.

Students will view the images. Students will set up a table or chart to record their observations of what color display is exhibited in the photographic image.

Students will determine whether the image primarily reveals the cephalopod's use of chromatophores, iridophores, leucophores, or photophores or a combination of these.

Answers to Student Data Table:

Photographic image #283: The chromatophores are clearly visible in these developing octopuses.

Photographic image #577: The entire body of this mid water squid is covered with photophores.

Photographic image #620: This is the deadly tiny blue ring octopus from the Pacific. While chromatophores are responsible for a lot of the animal's color, the bright blue rings are caused by iridophores.

Photographic image #761: Chromatophores are the obvious choice again. However, leucophores are likely also involved in the zebra display on a common cuttlefish.

Photographic image #1414: Clearly chromatophores are used here too, but this image of a *Sepia pharoanis* zebra display is a good example of iridophores which are responsible for the red and blue-green colors. Leucophores are likely also involved.

Photographic image #1415: This image is of the inside of a nautilus shell. The primitive nautilus doesn't have the color changing ability of the other types of cephalopods. Plus this is an image of a shell, not of an animal's skin. Even if the image did show the skin of a live nautilus, these animals simply don't have the ability to change their appearance like the other cephalopods. So there are two reasons why this image contains no chromatophores, iridophores, or leucophores.

Answers to Student Analysis:

1. The most common color change method is the use of **chromatophores**.

2. The deadly blue ringed octopus used **iridophores**.

3. Students should include all four methods in their paragraph: chromatphores, iridophores, leucophores and photophores.

Student Activities: How Cephalopods Change Color

By Brian Goldstein, Valerie Cournoyer, Roger E. Goss, Nancy W. Goss, and Dr. James B. Wood

Activity

Students will observe color changes in cephalopods by using the CephBase website. Students will determine whether the image primarily reveals the cephalopod's use of chromatophores, iridophores, leucophores, or photophores or a combination of these to change color.

Description

The CephBase website contains 1,642 photographic images and 144 videos of cephalopods. Using selected photographic images, students will view cephalopods to complete a data table and answer questions concerning how cephalopods change color.

Materials & Activities

- CephBase website, http://www.cephbase.utmb.edu/
- Or color photos of the pictures from the website listed above
- Vocabulary terms from How Cephalopods Change Color
- Paper and pencil to complete the data table

Procedure

1. Practice observation skills by viewing photographic images of cephalopods displayed from the CephBase website. Below are the numbered photographic images and a brief description.

2. Set up a table or chart to record your observations.

3. Determine primarily whether the photograph reveals the cephalopod's use of chromatophores, iridophores, leucophores, or photophores or a combination of these.

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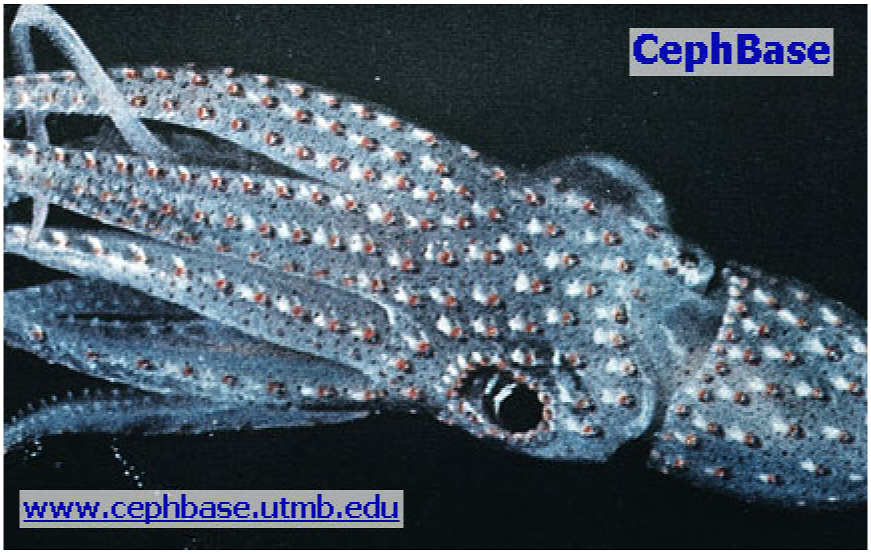
Use the following images from CephBase:

CephBase 283. James B. Wood



CephBase 577, James B. Wood

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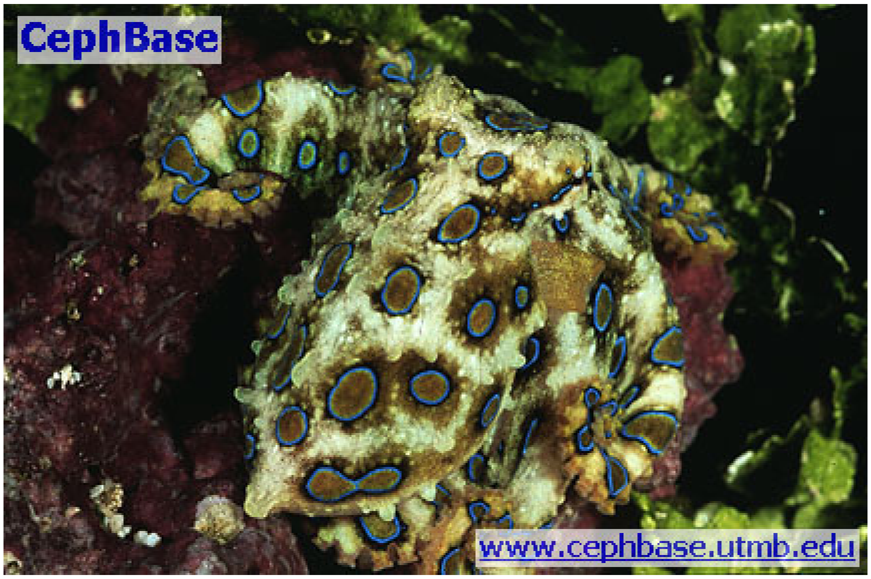

CephBase 620. Roy L. Caldwell

CephBase 761. James B. Wood

CephBase 1414 James B. Wood

CephBase 1415 James B. Wood

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4. Complete the Data Table for How Cephalopods Change Color

Photographic Images	**Color Change Due to:**				
	chromatophores	**iridophores**	**leucophores**	**photophores**	**combination**
Image # 283					
Image #577					
Image #620					
Image #761					
Image #1414					
Image #1415					

Analysis Question

1. Based on the data table, what is the most common method used to change color?

2. What method is responsible for the metallic rings in the deadly blue ringed octopus?

3. Write a summary of what you have learned by viewing these photographic images of cephalopods. Include the four ways in which cephalopods display color.

Acknowledgments

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