

# Porphyrins: The Colors of Life

**Zhang Research Group**

**Department of Chemistry**

**Boston College**

What do all these things have in common? This.....

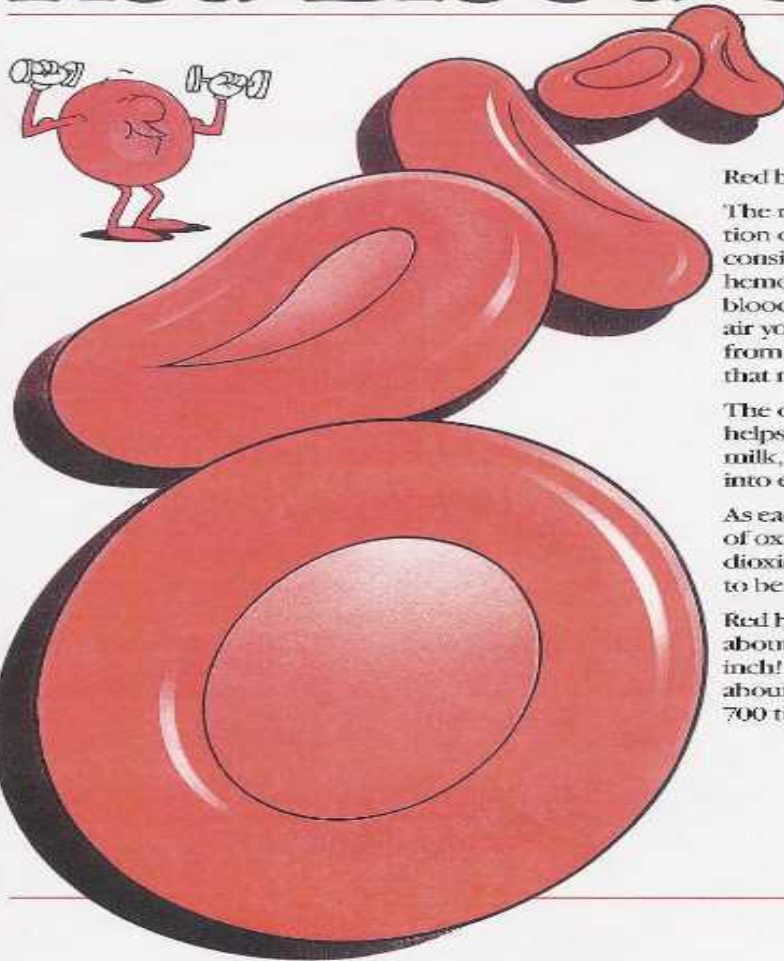


And....



# AND.....

## Red Blood Cells



Red blood cells give your blood its color.

The red color comes from a combination of oxygen and hemoglobin, which consists of iron and other materials. The hemoglobin makes it possible for red blood cells to pick up oxygen from the air you breathe and to carry that oxygen from your lungs to the trillions of cells that make up your body.

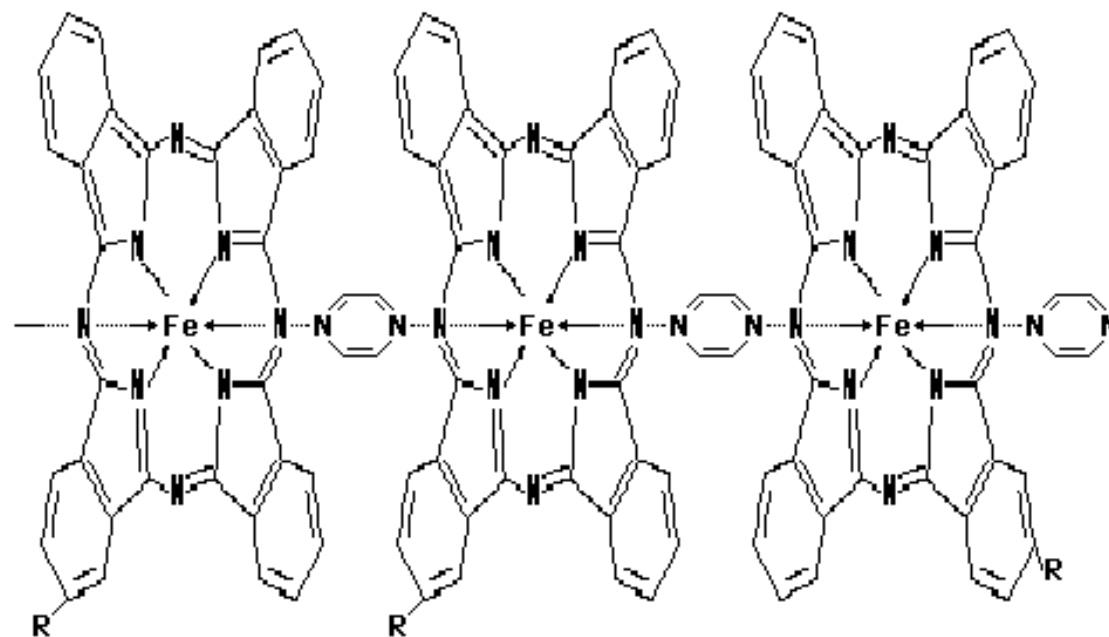
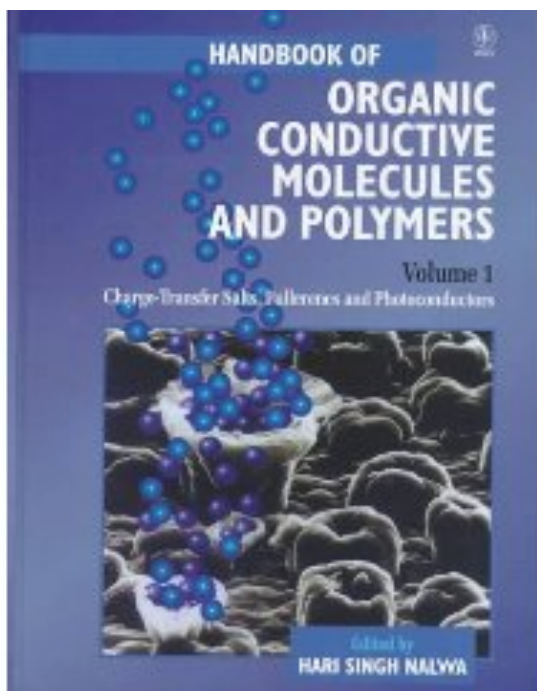
The oxygen released by the red cells helps convert nutrients in food such as milk, red meat, and green vegetables into energy.

As each red blood cell distributes its load of oxygen to the cells, it picks up carbon dioxide and carries it back to the lungs to be breathed out.

Red blood cells are round and tiny—about 3,000 end-to-end would equal 1 inch! An average adult's body contains about 25 trillion red blood cells—600 to 700 times as many as white cells!

American  
Red Cross 

# AND.....



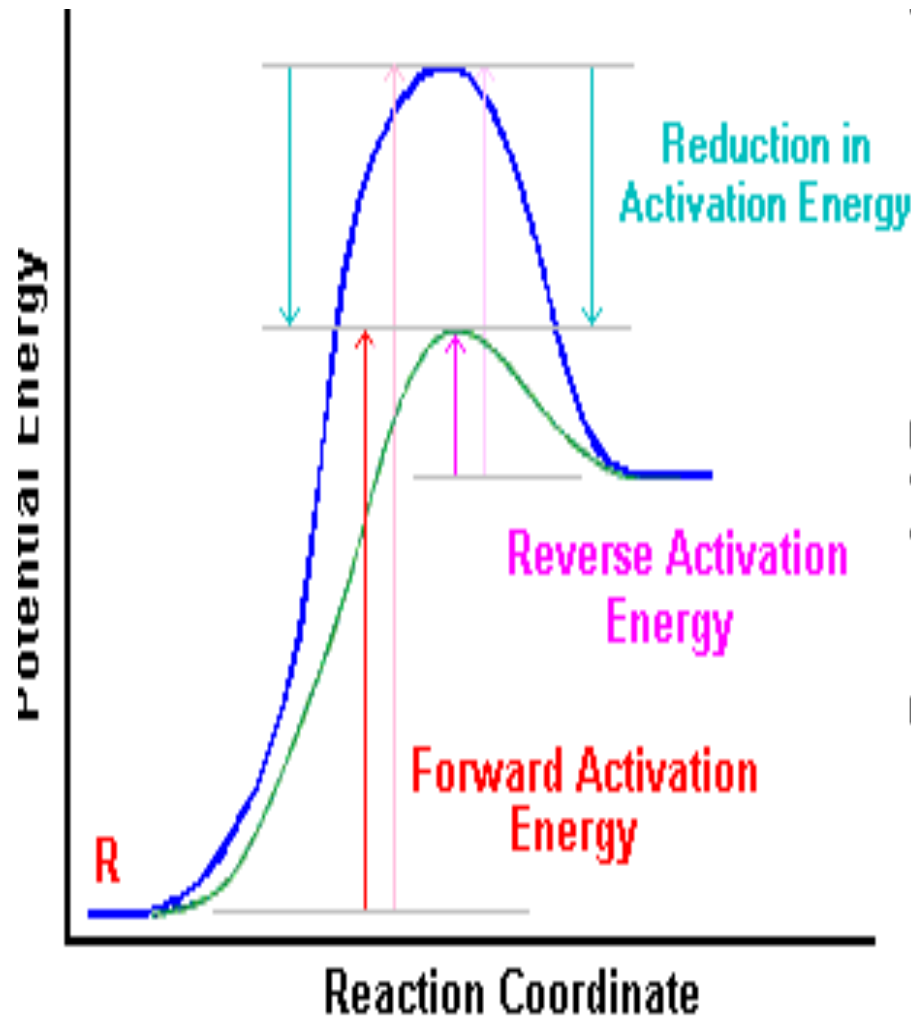
And



and



# And....

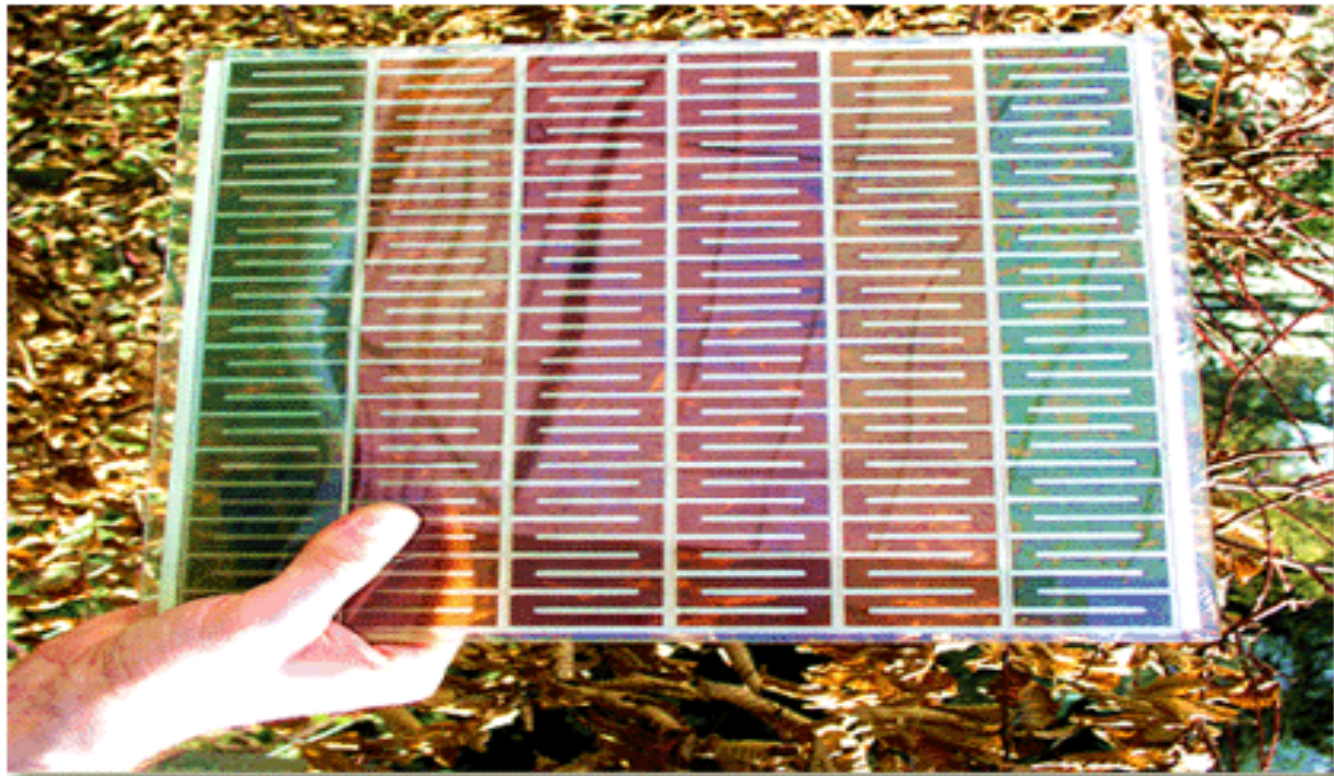




and

see how solaris technology transforms...

SOLAR ENERGY



And even.....



They all involve a class of  
chemical compounds known as  
**porphyrins**

# History of Porphyrins

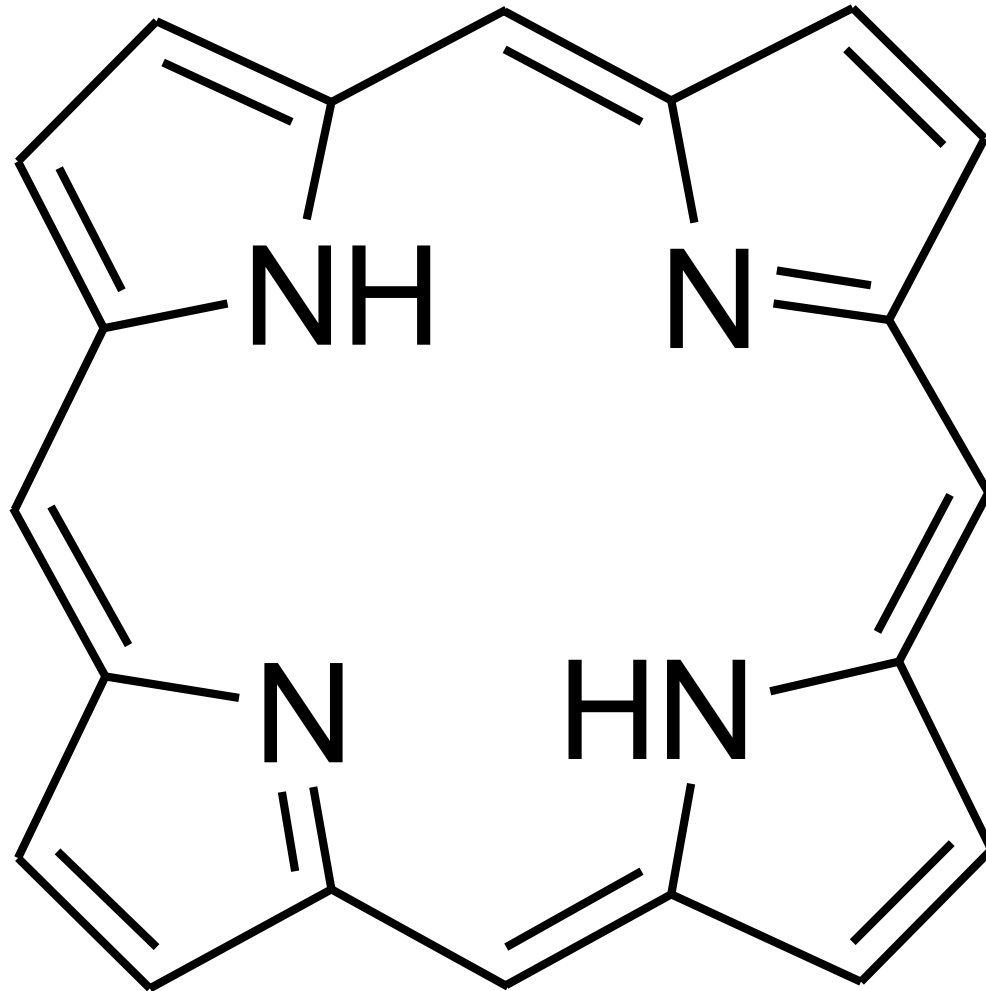
- The pathway to porphyrins begins with dyes extracted from plants such as the indigo plant. They were so brilliantly colored and colorfast that they quickly became a luxury. “Royal Purple”



# Porphyrins were discovered by accident!

- In 1897, a new German company (BASF) began manufacturing synthetic indigo dye, which was cheaper and easier than the extraction process.
- Another company, ICI, trying to make a modified indigo, kept getting a purple by-product that contaminated their desired product.
- These impurities were also brilliantly colored dyes, which could withstand temperatures up to 500C! Most other dyes would fade or turn colors at high temperatures.

Voilà! – le Porphyrin



# Why Porphyrins are Cool

- They're really big.
- They can contain many different metal atoms in their centers.
- They are very stable due to their *conjugation* (alternating single and double bonds).
- They can take on an amazing variety of roles in the real world, which is why they are widely utilized and researched.....

# Uses of Porphyrins

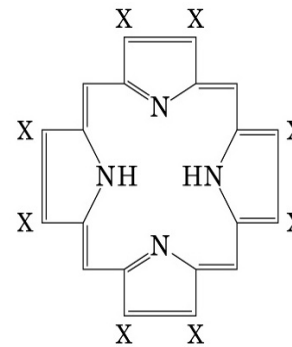
- Because of the unique chemistry of porphyrins, they are able to serve in several ways:
  - As a metal binder (ligands)
  - As a solar cell (convert light or chemical energy)
  - As an oxygen transport medium (hemoglobin)
  - As an electron transfer medium (conducting polymers)
  - Gene regulation
  - Drug metabolism
  - Iron metabolism
  - Hormone synthesis



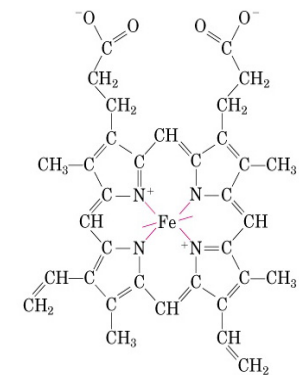
# As the basic building block of hemoglobin, and as a hemoglobin modeling molecule

- Heme – a cross-coupled porphyrin used in the larger molecule hemoglobin

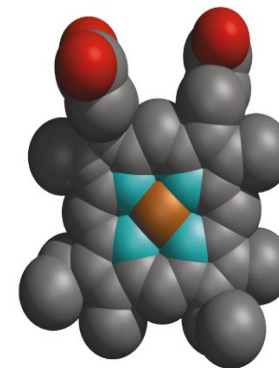
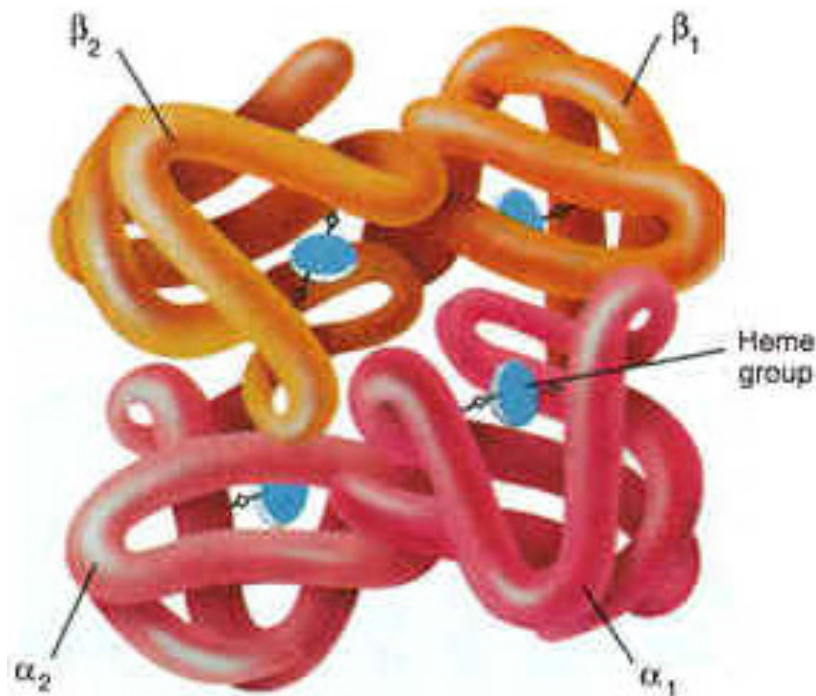
Heme Structure



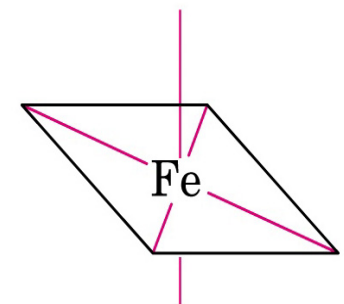
(a)



(b)



(c)



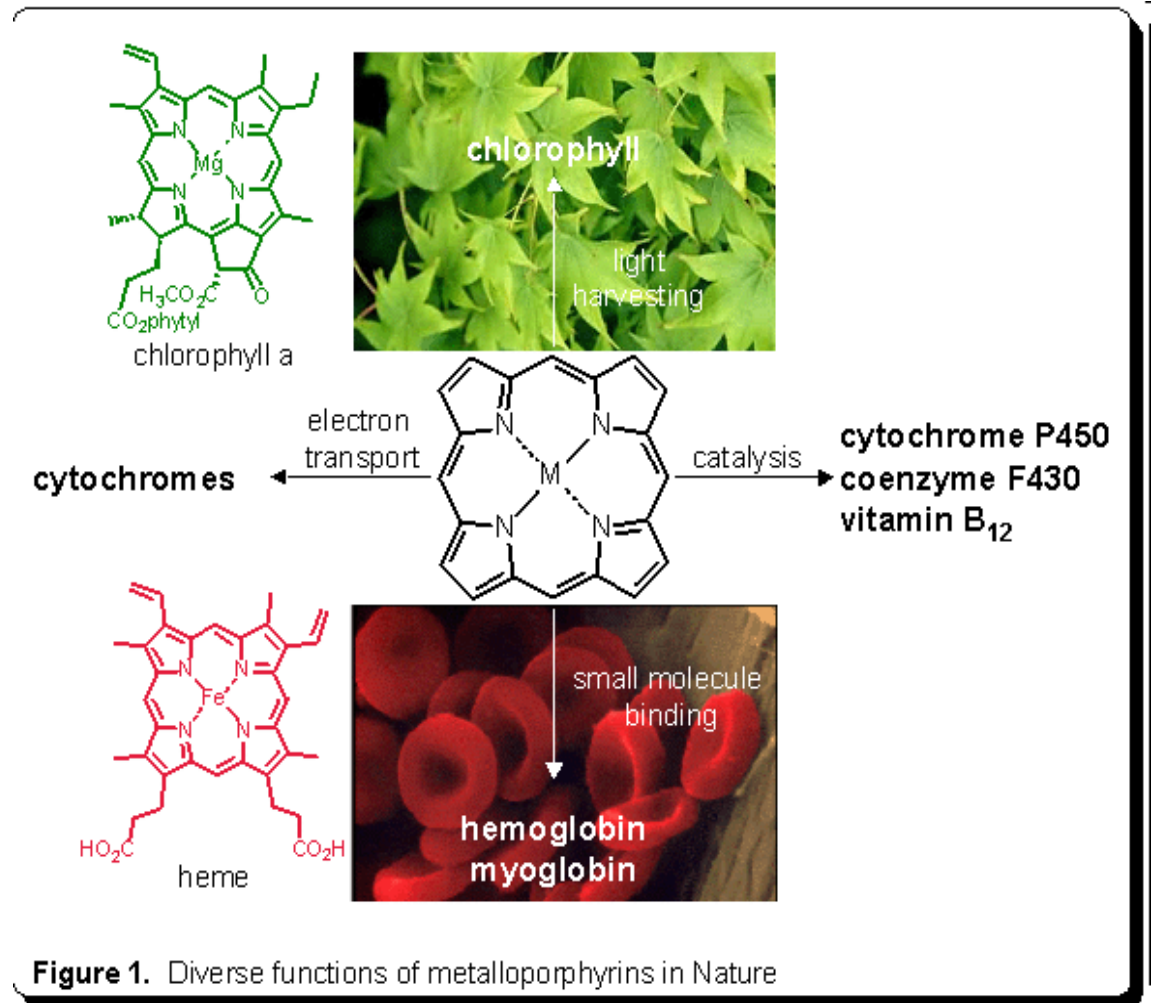
(d)

# Chlorophyll – yes, porphyrins are important in plants, too!

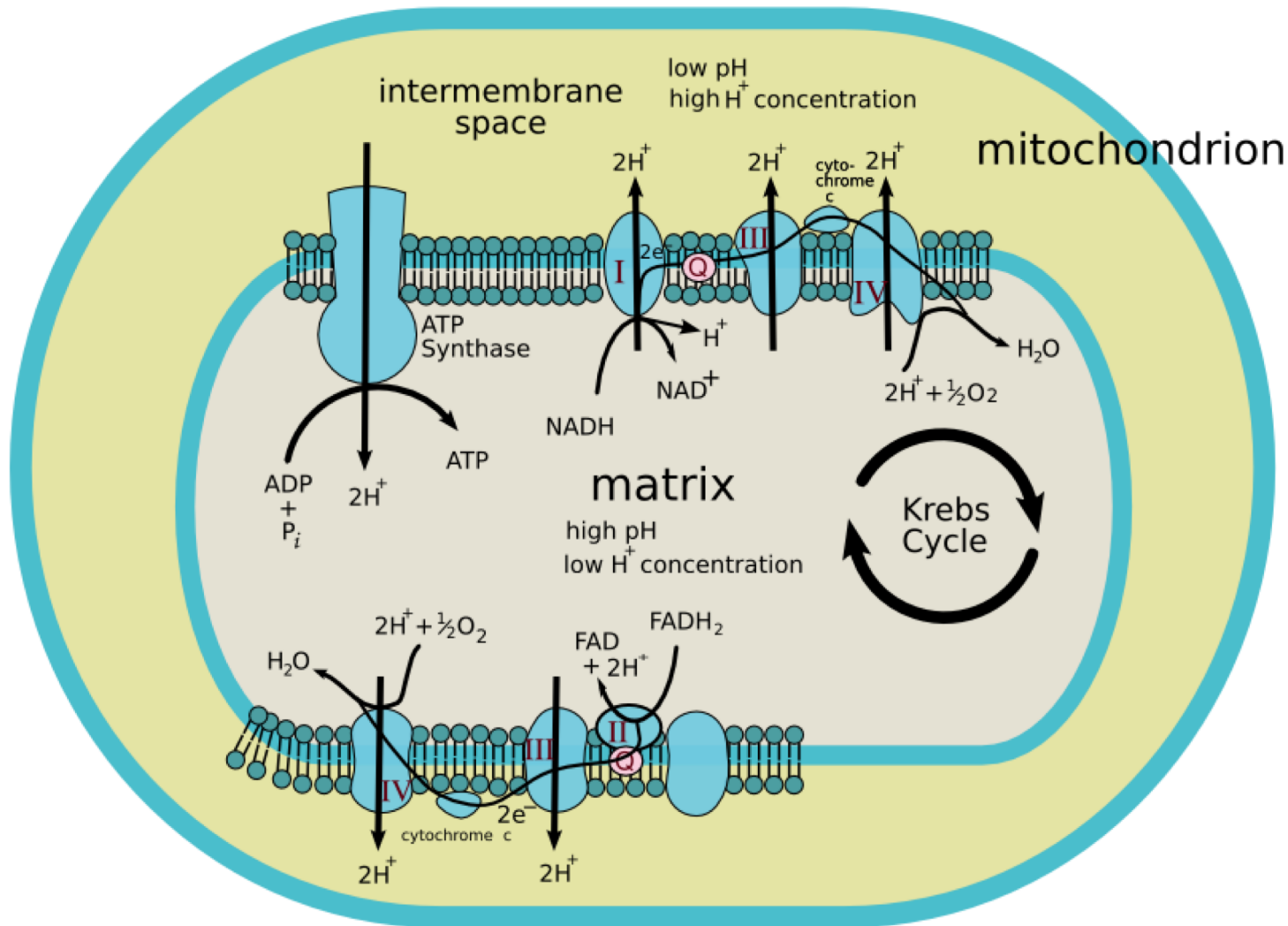
## Chlorophyll as a Photoreceptor

- Chlorophyll is the molecule that traps this 'most elusive of all powers' - and is called a photoreceptor. It is found in the chloroplasts of green plants, and is what makes green plants, green. The basic structure of a chlorophyll molecule is a [porphyrin ring](#), coordinated to a central atom. This is very similar in structure to the heme group found in hemoglobin, except that in heme the central atom is iron, whereas in chlorophyll it is magnesium.

<http://departments.colgate.edu/chemistry/images/geier-fig1.gif>



# Mitochondrial Electron Transport Chain

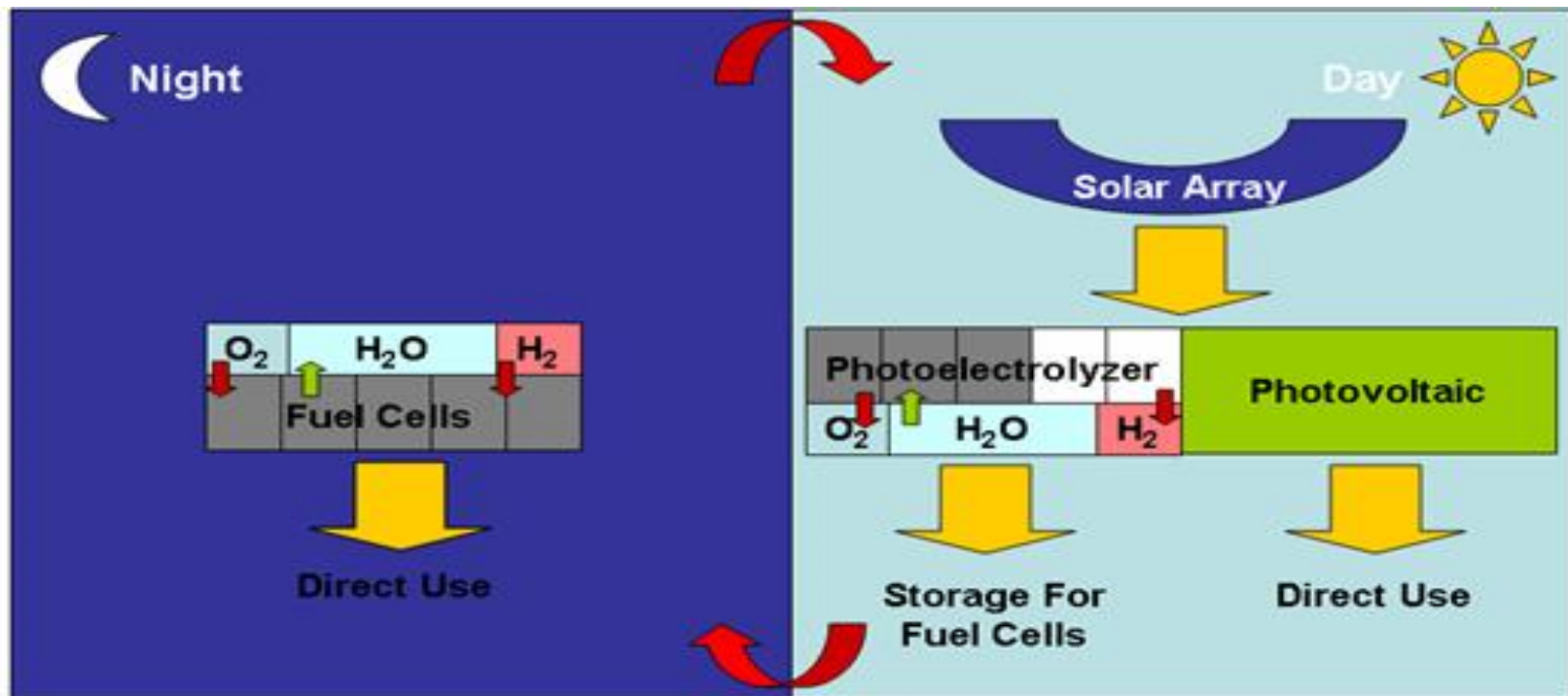


Cytochrome C – a molecule responsible for transporting an electron used to provide energy to the organism.

These molecules are identical, or very similar, for related species of plants or animals. For example, chickens and pigs have identical cytochrome C, and ducks differ only by a few atoms.

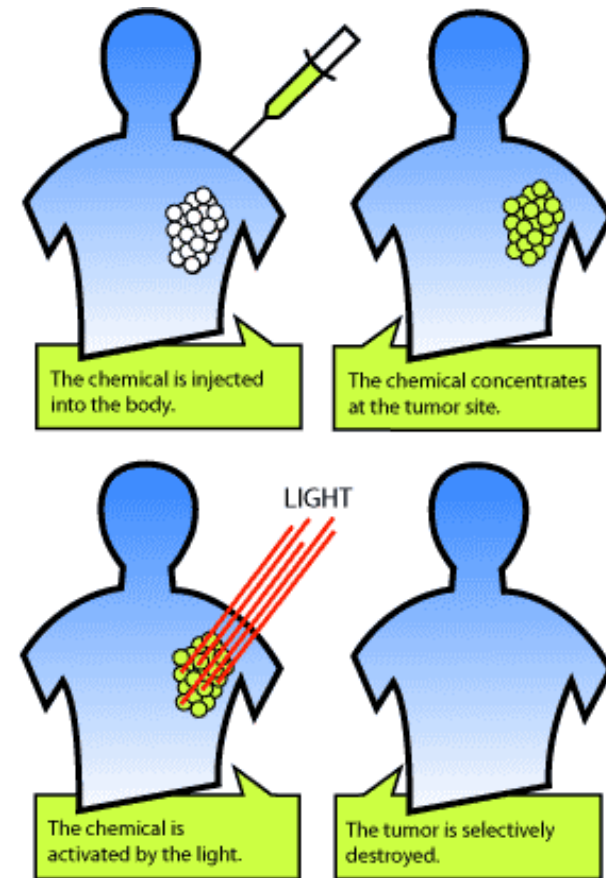
# As water-splitting molecule in fuel cells – they produce hydrogen gas from water

*The continuous system, during the daytime porphyrin-based photovoltaics are used directly for power needs. Some of the fuel cells are also run backwards for water splitting, which is then stored chemically as hydrogen and oxygen. Chemical storage is a more viable option compared to batteries in terms of efficiency and weight. The stored hydrogen and oxygen is fed into the fuel cells at night for continued use.*



# Photodynamic Therapy

- Porphyrins are commonly used as light-absorbing compounds which are “switched on” by photons of light and then react with cells in a desired way.



# Photodynamic Therapy

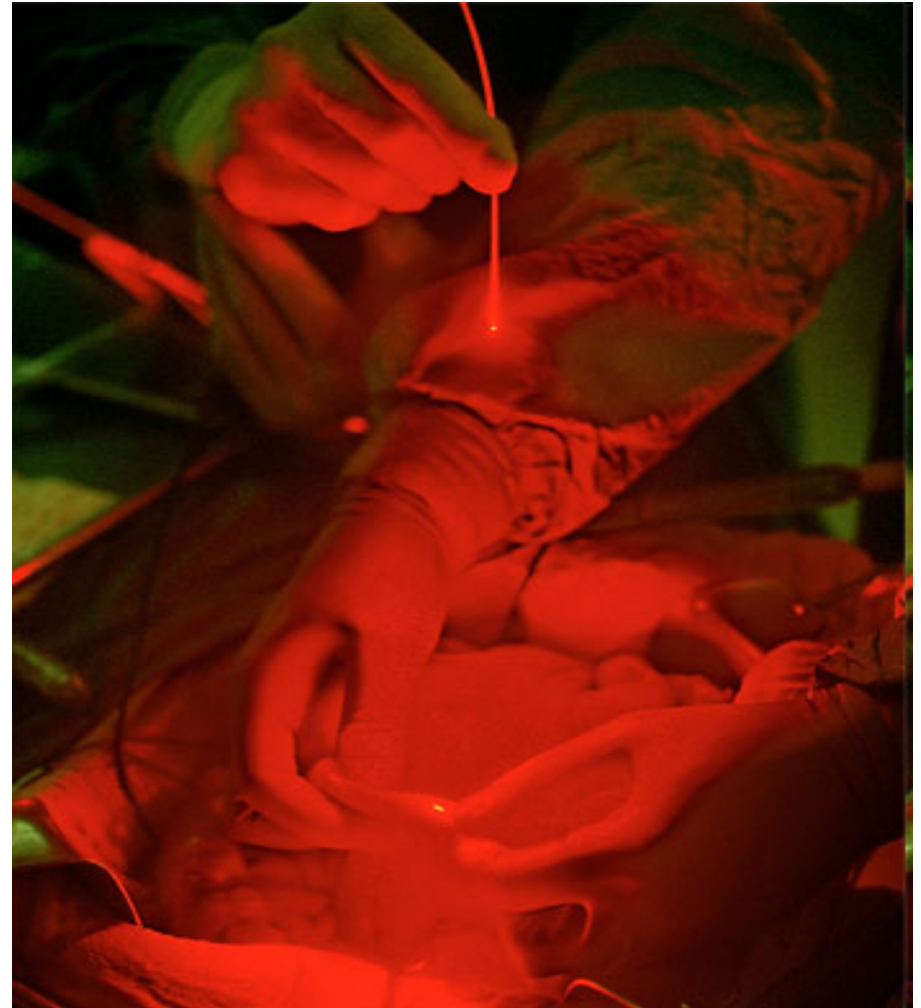
## Photodynamic therapy (PDT) -fiber optic surgery

A photosensitive drug absorbed by cancer cells can be activated by a laser beam guided through optical fibers to selectively destroy a tumor.

These drugs are also used to treat other conditions, such as acne.

*John Crawford—National Cancer Institute*

"*photodynamic therapy*." Online Photograph. Britannica Student Encyclopedia.  
9 July 2008 <<http://student.britannica.com/eb/art-92509>>.



# As an anticancer agent in photodynamic therapy

<b>Cancer type</b>	<b>Gross incidence pa</b>	<b>Suitable for PDT</b>
<b>Head and neck (oral cavity, larynx, pharynx and oesophagus)</b>	150,000 w/w based upon a US incidence of 17.7 per 100,000	Estimated 10% = 15,000
<b>Lung cancer</b>	500,000 w/w based upon a US incidence of approximately 170,000	Estimated 10% = 50,000
<b>Bladder</b>	150,000 based upon a US incidence of 53,000	5% = 7,500
<b>Gastric</b>	Second most common cancer in Far East 120,000 pa in Japan. Less common in West but w/w incidence must exceed 300,000 pa	Estimated 10% = 30,000
<b>Cervical</b>	40,000 based upon a US incidence of around 13,000	Estimated 10% = 4000
<b>Non melanoma skin</b>	500,000	Estimated 80,000
<b>Barrett's oesophagus(pre-cancerous)</b>	1 million US	5% =50,000
<b>Total potential patients</b>	<b>= 164,500 patients</b>	

Table: potential PDT cancer market

Sources: PDT Inc, SEER Cancer stats and various others. Estimates by First Instar other percentages PDT

# As chemical markers in oil exploration - Porphyrins

- The presence of metalloporphyrins in organic-rich sediments such as oil shales and petroleum, generally known as petroporphyrins or geoporphyrins, was first established in the 1930's.
- Deoxophylloerythroetioporphyrin (DPEP) and etioporphyrin-III, which usually occur as the nickel(II) or vanadyl chelates, are commonly found in oil and oil shale.
- DPEP is considered to be a 'molecular fossil' of the chlorophylls due to the presence of a five-membered exocyclic ring
- In the 1960's, mass spectrometric investigations demonstrated that sedimentary porphyrin fractions contain complex mixtures of metalloporphyrins.
- Indeed, more than eighty porphyrin structures have been identified in organic-rich sediments by mass spectrometry and NMR spectroscopy.
- These geoporphyrins fall into several major families, the most prevalent being the DPEP series which are structurally related to chlorophyll.
- The structures of the porphyrins in fossil fuels can provide insights into the origins of these materials and their sedimentary history, as well as being useful chemical markers for petroleum exploration.
- In addition, the porphyrins associated with a given sediment provide a unique fingerprint and may allow the origins of environmental contaminants (e.g. oil spills) to be ascertained.



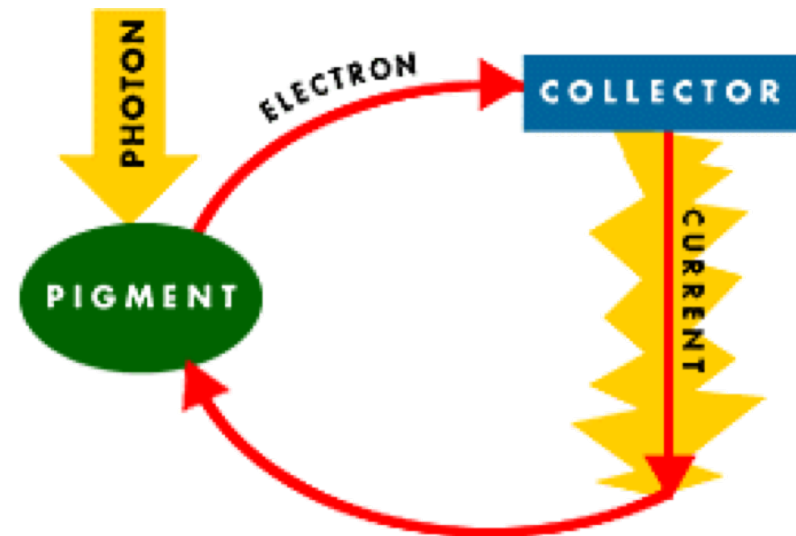
# In Conducting Polymers

- “Photovoltaic coatings that gather light and emit electricity could be used to power your house or your vehicle. If your vehicle was painted with a photovoltaic coating it could gather sun light and emit the electricity needed to power itself. This would be environmentally friendly and in most cases cheaper than petroleum products. “

– History & Coating Applications of Conductive Polymers Report for [Chemistry 446](#), Spring 2002 by Jason Shaw & Derek Marin

# Polymeric Photovoltaics

- A house that generates its own electricity and clothing that can power a laptop will soon become a reality. One may ask how this is possible? The answer is polymeric photovoltaics.
- While photovoltaic clothing products are almost here the photovoltaic structural coatings are still a ways off. Things are developing quickly in the field. All that remains is to make the coatings more efficient and cheaper to manufacture.
- One major area of research is *photovoltaic pigments* to augment coatings. A popular choice are the **porphyrins**, which are chemically similar to chlorophyll.

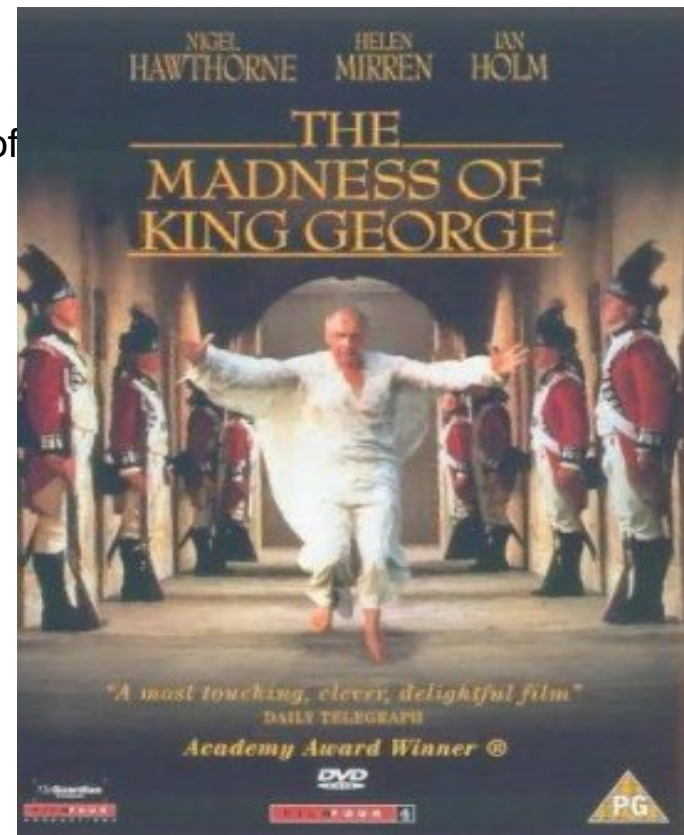


# Porphyria

•What made King George III so very mad? The British ruler who presided over the loss of the American colonies in 1776 was diagnosed about two centuries too late with porphyria — a genetic disorder that causes psychiatric disturbances, among other things.

- Multiple enzymes are needed for the body to produce heme.
- If any one of the enzymes is abnormal, the process cannot continue and the intermediate products, porphyrin or its precursors, may build up and be excreted in the urine and stool.
- As a result of feedback, the decreased production of heme leads to increased production of precursors, PBG, being one of the first substances in the porphyrin synthesis pathway.
- The hepatic porphyrias primarily affect the nervous system, resulting in.....

Abdominal pain	vomiting	acute neuropathy
seizures	hallucinations	depression
anxiety	cardiac arrhythmias	fast heart rate (tachycardia)
Chronic and acute pain	paranoia	Constipation and/or diarrhea

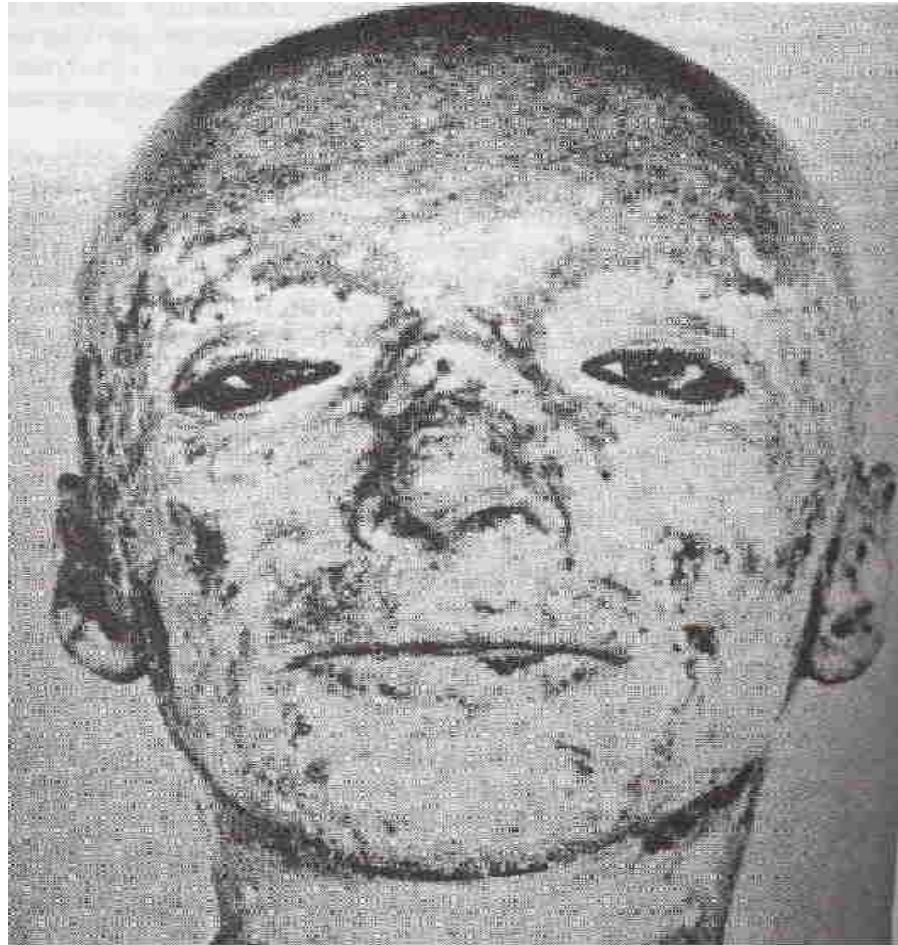


# The Truth about Vampires?

- Photosensitivity? Crazy behavior? Pale skin? Anemic? “Involuntary transfusions”?
- Stories of vampires date back thousands of years. Our modern concept stems from Bram Stoker's quirky classic Dracula and Hollywood's Bela Lugosi--the romantic, sexually charged, blood-sucking outcast with a fatal susceptibility to sunlight and an abhorrence of garlic and crosses.
- In contrast, vampires of folklore cut a pathetic figure and were also known as the undead.
- In searching for some underlying truth in vampire stories, researchers have speculated that the tales may have been inspired by real people who suffered from porphyria.
- Did they seek the blood of others because they were unable to manufacture their own? Hmmmm.....



# Werewolf?

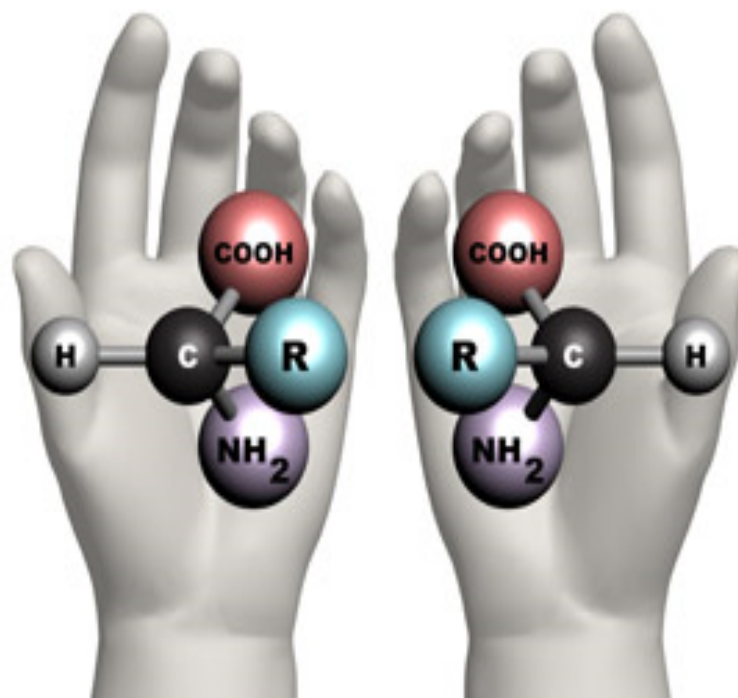


A porphyria blood disease patient -- what had been mistaken as lycanthropy, aka "werewolfism"

<http://www.geocities.com/RainForest/Canopy/5322/molybdenum.html>

# As a selective catalyst

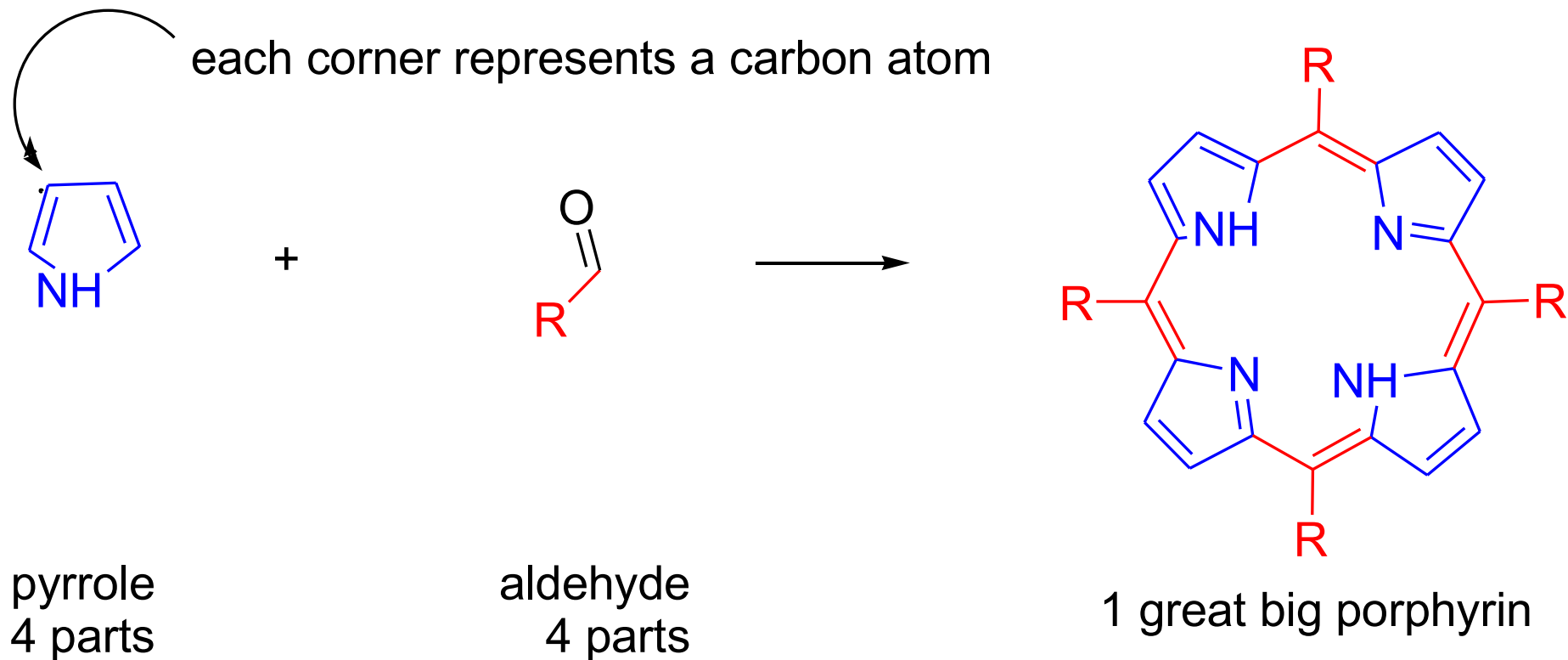
- Porphyrins, especially those with special groups known as chiral centers as part of the structure, have a special ability to help chemical reactions to proceed to very specific products.
- Chiral centers are carbon atoms with four different groups attached to it.



# A Quick Organic Chemistry Lesson

- Organic chemistry – the chemistry of **carbon**-containing compounds
- Shortcut formula – draw lines instead of carbon-carbon bonds.
- R – a letter used to represent a variety of carbon-chains from one carbon to many.

# Synthesis of Porphyrins Simplified



(R is hydrogen or a carbon chain of any length)

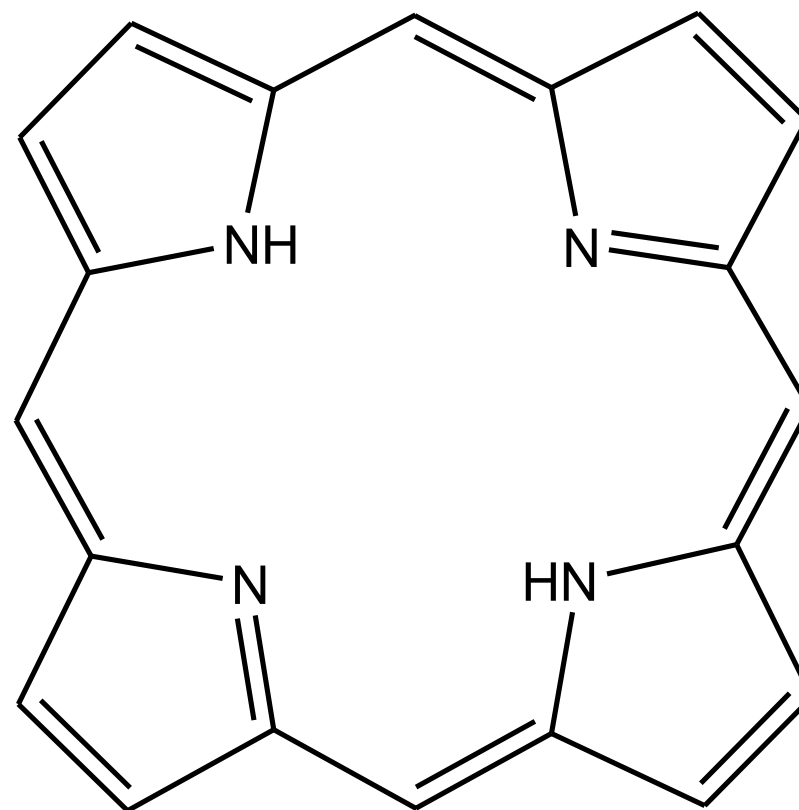


# The Porphyrin Synthesis Process

- Reaction: Pyrrole and aldehyde
- Separate product (porphyrin) from leftover reactants and by-products
- Purify (by chromatography) and remove water and/or other impurities
- Wash and filter as needed to isolate product

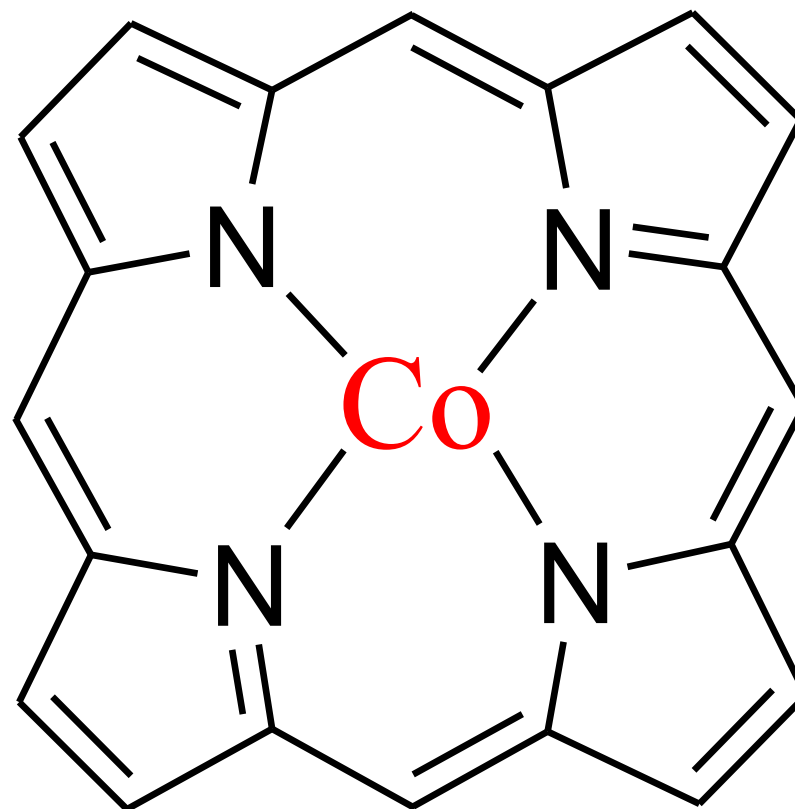
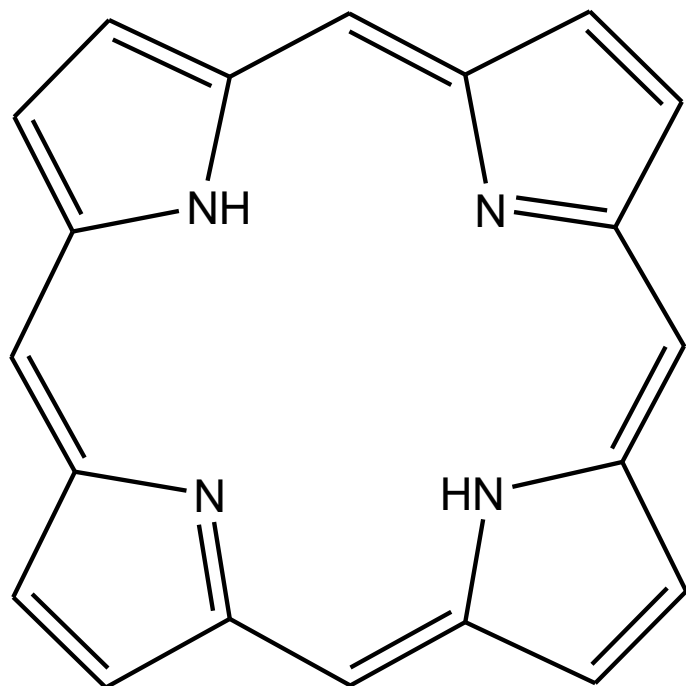
# Porphyrin Research

- What is there to research? Aren't they all pretty much the same?
- Well, no. There are lots of variations. There is the "base model" →
- And then there are lots of *substituted* porphyrins.
- So you can change the groups attached to it, and when you do, it gets new characteristics.



# Porphyrin Variation 1 – the Center

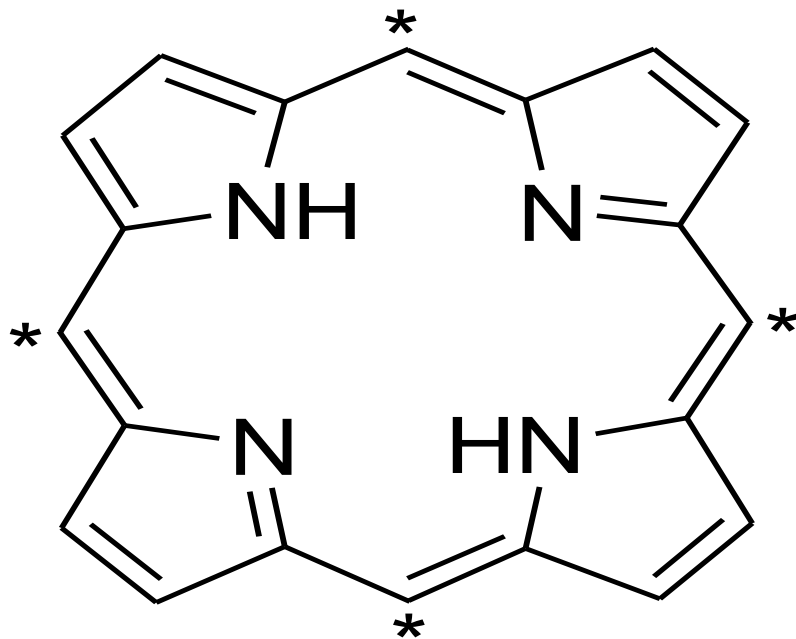
- The center of the porphyrin can be empty (left) or hold a metal ion (right). This is called *coordination*. The porphyrin on the left is empty, while the one on the right contains a cobalt atom.



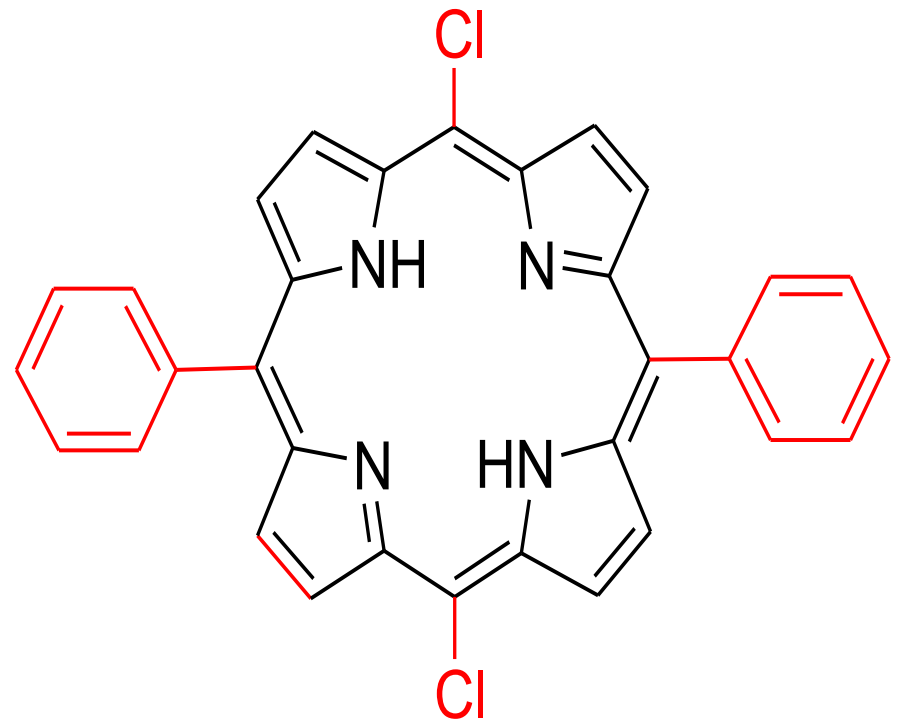
# Porphyrin Variation 2

## The Meso Positions

- Different functional groups (“R”) can be attached to one or more sides. Imagine all the different combinations of many possible functional groups mixed and matched at these four locations



meso positions\*

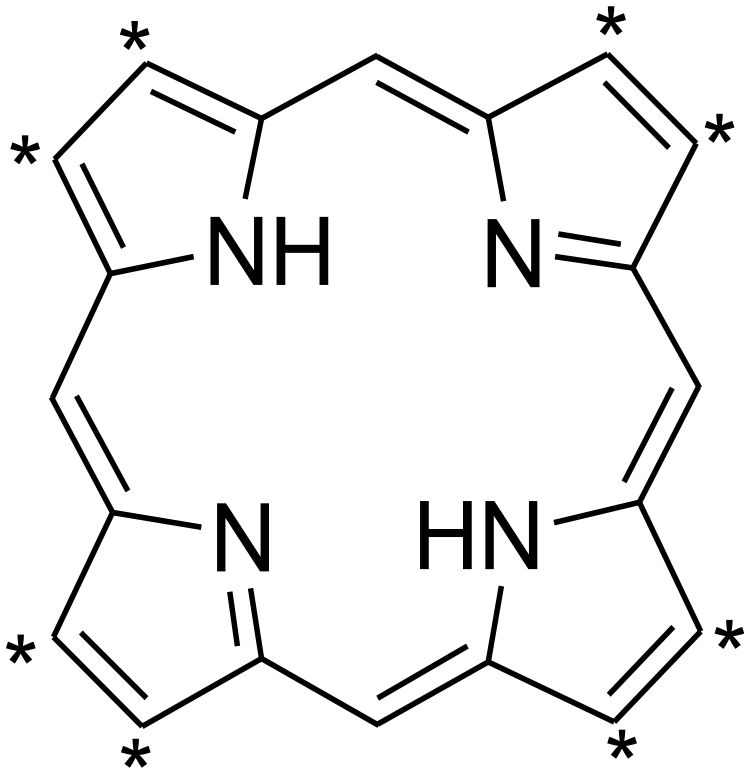


meso-substituted porphyrin

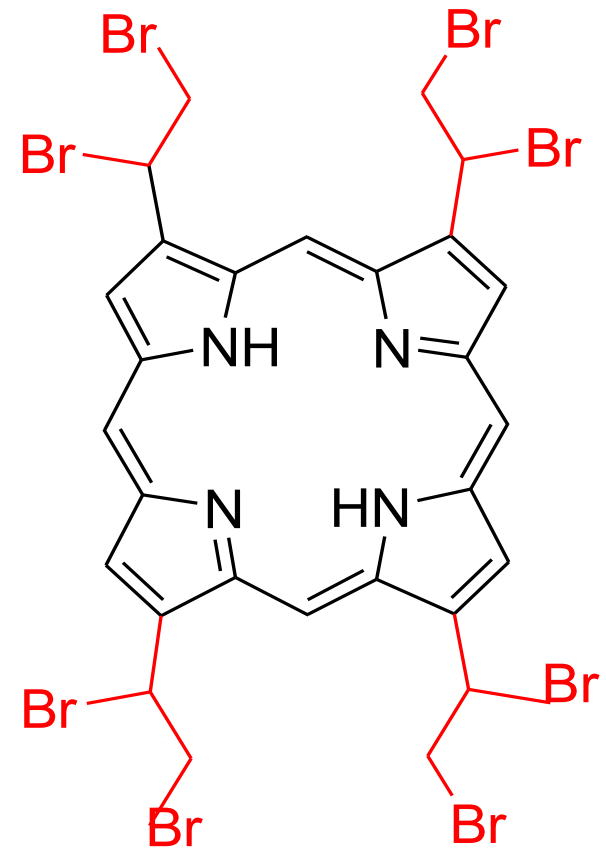
# Porphyrin Variation 2

## The Beta Positions

The beta positions are the corner positions.



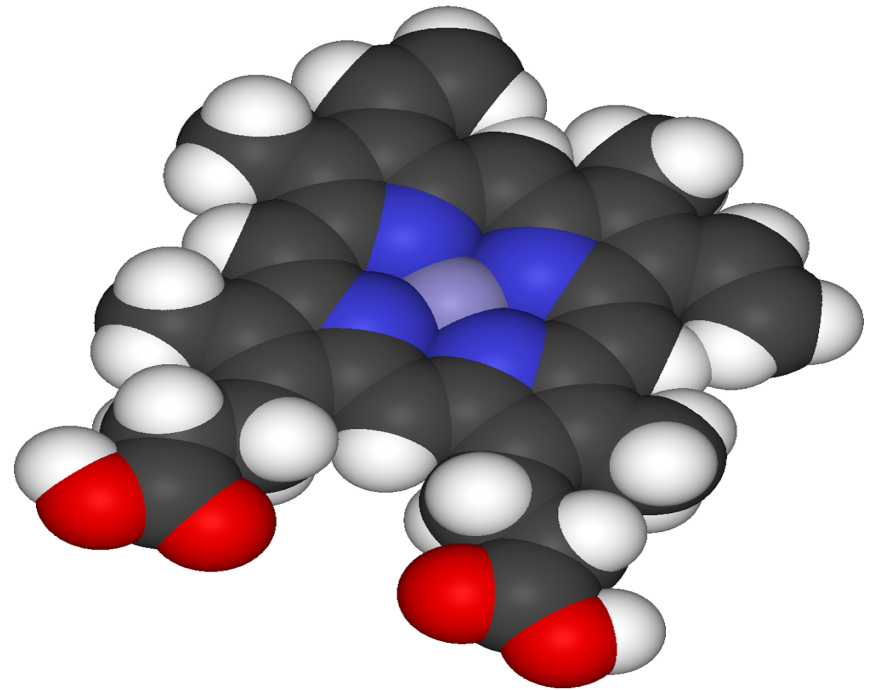
beta positions (asterisks\*)



beta-substituted porphyrin

# Porphyrin Variation 3

- Combinations of these combinations!  
Coordinated Metals  
*and/or* Meso-substituents  
*and/or* alpha-substituents  
*and/or* beta-substituents



Heme B

# Chemical Research Is....

- Discover new compounds and their properties
- Discover how the new compounds function
- Publish findings worldwide so others doing similar work can learn from it, question it, collaborate, etc.
- Research sometimes leads to recognition, advancement, and other perks. But even when it doesn't, it always adds to the collective body of knowledge, some of which may be valuable later.
- For example, (late discovery example)

# BC Leadership in Porphyrin Research

- Synthesis of new porphyrin catalysts – introducing new groups to the porphyrin periphery
- Use of synthesized novel porphyrin catalysts in various highly-specific synthesis reactions



# What Does it Take to Be a Research Chemist

- Graduate high school – take as much science as you can, especially AP courses
- Get a bachelor's (4-year) degree in a major such as chemistry, chemical engineering, biology, or anything else with a good chemistry foundation
- Apply to Grad school... they usually will pay you to go! (don't get excited though, it's not a lot)
- Pick a program and do teaching, research, and probably a few other duties
- Defend your doctoral thesis and they make you a doctor!

# Benefits - PhD Degree in Chemistry

- You will in your lifetime earn about significantly more than the master's and bachelor's degreed people alongside you.
- You will most likely be a specialist or manager or other similar lofty position
- You likely will get to travel but not too much
- You will live to an old age..... (really)
- Your job will be interesting and ever-changing

# Acknowledgements

- National Science Foundation
- URF Awards; Boston College
- BC Department of Chemistry
- USF Department of Chemistry
- REST Program, Florida Department of Education
- School District of Hillsborough County
- Paul Goodland
- Kimberley Fields
- Jessica Paziienza