Logout

ANSWER KEY
for
"The Mona Lisa Molecule: Mysteries of DNA Unraveled"

by
Karobi Moitra
Department of Biology
Trinity Washington University, Washington DC

---

1. Taking the clues from the diary entry, speculate on what Francis Crick and James Watson had discovered.

Francis Crick and James Watson had discovered the structure of DNA. Several clues from the diary point to this fact, such as, the names of James Watson and Francis Crick, mention of the Cavendish laboratory, the mention of the famous pub, the Eagle, and Francis Crick's statement about discovering the secret of life.

2. Why do you think that he specifically mentioned that they had "discovered the secret of life itself"?

Genetic material is the basis of all known life on Earth. By solving the structure of DNA, Watson and Crick had discovered the template/blueprint on which most forms of life are built (*Note:* the word "most" is used because of the existence of retroviruses with RNA as the genetic material).When Watson and Crick solved the structure of DNA, and saw the complementary base pairing, they immediately visualized a mechanism by which the DNA could serve as a hereditary molecule. This indicated that DNA was the blueprint of life. This is the reason for their famous final sentence in their paper "it has not escaped our attention that the structure of DNA immediately suggests a mechanism …"

3. Why was it important to solve the structure of DNA?

It was important to solve the structure of DNA in order to understand how the genetic material could replicate and decode the genetic information in order to direct the synthesis of RNA (and ultimately proteins).

4. How do you think that solving the structure of DNA could move the field of genetics forward?

Solving the structure of DNA not only moved the field of genetics forward by pointing to the solution of how DNA could act as a template for the synthesis of new DNA, but also was the basic cornerstone of the new field of molecular biology. Molecular biology deals with the molecular basis of biological activity in cells, especially the interactions between DNA, RNA, and proteins. By solving the basic structure of DNA, Watson, Crick, Wilkins, and Franklin provided the conceptual foundation for the discovery of many biological processes and techniques, such as DNA replication, transcription, protein synthesis, gene cloning, and genome sequencing, etc. This in turn led to many medical advances, including the treatment for a number of genetic diseases through the process of gene therapy.

5. Go to the websites: http://www.dnai.org/ and http://www.nature.com/nature/dna50/index.html. With the aid of the information on the websites, explain how the Hershey-Chase experiment conclusively proved that DNA and not protein was the genetic material.

The Hershey-Chase Experiment (1952) conclusively proved that DNA and not protein was the genetic material. The DNA of bacteriophages (a bacteriophage is a virus that can infect bacteria) was labeled with 32P (radioactive phosphorous). Phosphorus is only present in DNA (not protein), so by labeling the phosphorus only, the DNA would be tagged but not the protein. These bacteriophages (named T2 phages) were allowed to infect the bacterium *E. coli*.

In the second condition of the experiment, all of the proteins of the bacteriophage T2 were labeled with radioactive sulphur, 35S (35S can only label protein and not DNA). In either condition, *E. coli* was infected with these phages (separately for each condition). The solution was sheared in a blender to separate the phage ghosts (phage coats) from the infected bacteria and the phage viruses were given time to amplify in the host *E. coli*.

The protein tracer/tag was observed in the phage ghosts and did not enter the *E. coli*, whereas the infected bacteria were labeled with 32P (DNA tracer) as were the progeny phages. This proved that it was the DNA that entered the bacteria to replicate and be transmitted to the progeny phages and not protein.

6. What is "model building"? How can this technique be used to solve the structure of biological molecules?

Model building is the process by which models are built to simulate biological structures and then put together based on the basic principles of biochemistry. Back in the day, actual physical models were built using different types of materials. Nowadays, molecular models are built using computational software.

7. Describe the "bare bones" basic principle behind X-Ray diffraction.

The principle behind X-ray diffraction is that a crystal of the biological molecule of interest is created and this is bombarded with incident X-rays that are diffracted through the crystal in many specific directions to form an image on a photographic plate.

8. Explain very simply how the X-ray diffraction process aids in solving structures of biological molecules.

In order to solve the structure of a biological molecule, a scientist can measure the angles and intensities of the diffracted beams to form an electron density image (map) of the molecule from which the positions of the atoms (and other data) in the crystal can be calculated and the structure of the molecule can be visualized. In the present day, computers in a matter of minutes carry out these calculations. Rosalind Franklin and other crystallographers of her time, however, made these calculations without the help of a computer and this took months of complex calculations.

9. Compare and contrast the two techniques above (model building and X-ray crystallography) and discuss their usefulness in structure determination of biological molecules.

Model building can help depict the structure of a biological molecule and assist the scientist with visualizing what the molecule may look like. For instance, Watson and Crick built an actual physical model of DNA made out of metal. This would be similar to making a model out of, for instance, Lego bricks. However, X-ray crystallography produces the actual scientific data and can help to elucidate the correct structure of the molecule without too much guesswork (if the resolution of the crystallographic image is good enough). The "model" of the structure from the data is then computationally built using the very accurate data generated by the X-ray diffraction pattern. Both are useful in science. When crystals cannot be synthesized, molecular modeling is used as a computational tool to model the structure of a biochemical molecule using a similar molecule as a structural template. In the case of DNA, the initial model was built physically by hand using the X-ray crystallography data.

10. *Describe the building blocks of DNA in detail.*

The building blocks/basic units of nucleic acids are nucleotides. Nucleotides are composed of:

- A nitrogenous base
- A pentose (5-carbon) sugar called deoxyribose and
- A phosphate group

The nitrogenous bases can be either purines or pyrimidines. Purines are double ring structures and consist of adenine(A) and guanine(G). Pyrimidines are single ringed molecules and consist of thymine (T), cytosine(C), and uracil (U). Uracil is a component of RNA. In DNA, A always pairs with T (A-T) and G always pairs with C (G-C). This is called complementary base pairing.

A pentose sugar is a monosaccharide with 5 carbon atoms. In DNA the sugars are 2-deoxyribose, which means that the 2′ (the number 2) carbon does not contain an oxygen but rather contains only a hydrogen atom attached to it (hence, deoxyribonucleic acid; RNA contain the sugar ribose, which does have a OH group attached to the 2′ carbon).

Phosphate groups are negatively charged and acidic; hence DNA is negatively charged and is an acid. The phosphate groups join the sugars together to form the sugar-phosphate backbone on the outside of DNA.

11. *Define Chargaff's Laws.*

Chargaff's Laws are as follows: In double-stranded DNA, the number of guanine units is equivalent to the number of cytosine units and the number of adenine units is equivalent to the number of thymine units, A~T, G~C. Also, the composition of DNA nucleotides varies from one species to another. This means that the percentage of A/T versus the percentage of G/C is different in different species. Finally, the sum of the purines equals the sum of the pyrimidines, (A+G) = (C+T).

12. *Why were Chargaff's Laws important in regards to solving the structure of DNA?*

Chargaff's Laws were important because they suggested that adenine paired with thymine and guanine paired with cytosine, based on the fact that in double-stranded DNA the number of guanine units is equivalent to the number of cytosine units and the number of adenine units is equivalent to the number of thymine units, A~T, G~C.

13. *What critical pieces of information did Watson and Crick gather from the new X-ray crystallographic picture of B-DNA?*

Watson and Crick saw a cross-like reflection indicative of a helix. Furthermore, the 3.4Å meridional reflection indicated that the 3.4Å pyrimidine and purine bases were stacked on top of each other and X-ray images indicated that the diameter of the helix was 20Å, which suggested a double helical structure. A picture began to emerge from the data of 3.4Å bases stacked on top of each other in a helical structure of 20Å diameter. The model of DNA was based on this new data and on the (non-)scientific principal that "the best things in nature come in pairs"—this led to Watson deciding to build 2 chain models of DNA.

See the pictures at these websites: http://askabiologist.asu.edu/Rosalind_Franklin-DNA and http://en.wikipedia.org/wiki/Photo_51

14. *Why was the picture called photo 51? Who took this picture?*

The picture was called "photo 51" because it was the 51st picture that Rosalind Franklin had taken and she had labeled it as photo 51 in her laboratory notebook. Rosalind Franklin had taken this picture of B-DNA, the most common form of DNA.

See this website for additional information:
http://biowiki.ucdavis.edu/Genetics/Unit_I%3A_Genes,_Nucleic_Acids,_Genomes_and_Chromosomes/Chapter_2._Structures_of_nucleic_acids
Form,_A-Form,_Z-Form_of_DNA

15. *Do you think that Photo 51/ Rosalind's X-ray diffraction data was crucial to solving the structure of DNA? Why/Why not?*

Yes, because it contained critical pieces of data (see the answer to question 12).

16. *Answer the following basic questions regarding the structure of DNA:*

a. *Name the type of bond that holds the two strands of DNA together.*

Hydrogen bonds.

b. *Compare the components of a nucleotide versus that of a nucleoside.*

Nucleoside lacks the phosphate. A nucleotide is composed of pentose sugar, nitrogenous base, and phosphate, while a nucleoside only contains the pentose sugar and the nitrogenous base.

c. *What is meant by "antiparallel helix" as it pertains to DNA?*

One strand of DNA runs from the 5′ end to the 3′ end while the other runs from the 3′ end to the 5′ end. (5′ and 3′ denote the numbering of the carbons on the deoxyribose sugar.) To be more clear: The 5′ and 3′ mean "five prime" and "three prime," which indicate the carbon numbers in the DNA's sugar backbone. The 5′ carbon has a phosphate group attached to it and the 3′ carbon a hydroxyl group.

d. *Where is a glycosidic bond located in DNA?*

A glycosidic bond is nitrogen-carbon linkage between the nitrogen of purine/pyrimidine bases and the 1′ carbon of the sugar group. It is located between the sugar and a nitrogenous base.

e. *Which component of DNA imparts a negative charge to the molecule?*

Phosphates.

f. Write down the complementary strand of this DNA sequence:

5’ a t t t a g g g g c g a 3’
3’ t a a a t c c c c g c t 5’

17. Use Internet resources/articles/your textbook to determine how the structure from the 1953 paper has been corrected in recent times.

There are minor grooves and major grooves in B-DNA and also guanine and cytosine are held together by 3 hydrogen bonds and not 2 as originally depicted.

18. Create a time-line of key events leading up to solving the correct structure of DNA starting from the discovery of DNA as the genetic material.

Use the events in the diary to guide you with this activity. The following websites contain the answer to this question.
http://www.nature.com/scitable/topicpage/discovery-of-dna-structure-and-function-watson-397
http://unlockinglifescode.org/timeline?tid=4

19. Explain this statement in detail and its underlying implications: “It has not escaped our notice that the specific pairing we have postulated immediately suggests a copying mechanism for the genetic material.”

Since the base pairing is complementary (A-T, G-C), this indicates that the complementary base pairing is a way in which information can be chemically maintained and passed on from generation to generation. This principle was soon to become the basis of the central dogma of molecular biology, which in its simplest form states that DNA makes RNA, RNA makes protein (there are exceptions—such as in retroviruses).

20. What were Rosalind Franklin’s contributions to discovering the structure of DNA?

She solved the X-ray structure of B-DNA. When Watson and Crick looked at the photograph, the cross-like patterns immediately suggested a helix. The dimensions of the image also allowed them to figure out the vertical distance between the base pairs (3.4 Å) and how many base pairs there were per turn (10 base pairs per turn of DNA).

21. Do you think that the structure of DNA could have been solved without Rosalind’s X-ray diffraction data?

No (see answer to question 19 to learn why), but eventually another scientist would have probably produced some comparable data.

Optional Activities (To be determined by individual instructors)

1. Discuss the ethical implications of Rosalind Franklins X-ray picture being shown to Watson and Crick without her knowledge.

This is an open-ended question. Students should use the resources provided to answer this. Briefly, it would be considered unethical because Rosalind did not share her data directly with Watson and Crick. Watson and Crick based their structure of DNA on her X-ray data obtained in an illegal manner (without her permission). In counterpoint, the argument is that the data was published and available in a report and that since Rosalind had herself given the photo to Maurice Wilkins he was free to show it to whomever he wished.

2. How much has the outlook changed towards women in scientific fields changed since Franklin’s time compared to the present day?

Open-ended discussion question. Students should use the resources provided to answer this and also research independently. Briefly, there are some differences, for instance, back in the day a woman scientist who was able to speak her mind was labeled as being very dominating. Now-a-days, scientists whether male or female are expected to speak their mind and present their data without fear of being labeled as pushy or dominating. There are now laws in place to prevent discrimination against women in the workplace; during Rosalind Franklin’s time, there were none or very few. Rosalind was not permitted to enter the common room/lounge area at Kings College because it was designated for men only. She was also given a tiny basement laboratory (whether this was discrimination was debatable) and was not taken seriously as a scientist by the male-dominated science-field. Women during her time were not encouraged to take up science and were often not given full recognition for their work. Rosalind herself didn’t have a permanent job for a very long time even after doing such spectacular work on “holes in coal” (porosity of coal), DNA structure etc.

3. Write a five-page referenced paper exploring your view on the “iconic” imagery of the double helix in science, art, literature, and society. Use at least five primary sources or book references and a few web references if required.

Open-ended assignment. Students should use the resources provided to answer this and also independently research this paper. Briefly, the image of DNA is an iconic image. Nearly every educated person is familiar with the twisted pattern of the double helix. In nature, helices appear in the structure of biological macromolecules such as DNA and proteins and conjure up an imagery of mystery and beauty. In art, the double helix has been depicted in the paintings of Salvador Dali and in the brilliantly composed sculptures of Franco Castellucio, to mention but a couple of artists. So, what is this hold that the double helix has over us? How does the double helix define and shape our thinking? How does the image of the double helix impact our society? On a different note, faith and family are said to be the “double helix” of society, how did we get from science to society? These could be the types of questions addressed in the paper.
