CHAPTER 11 – DNA IS THE GENETIC MATERIAL

Figure 1.
Parent and offspring Wolf's Monkey.
(Flickr- Eric Heupel - CC BY-NC-ND 2.0)

INTRODUCTION

Genetics is the scientific study of heredity and the variation of inherited characteristics. It includes the study of genes, themselves, how they function, interact, and produce the visible and measurable characteristics we see in individuals and populations of species as they change from one generation to the next, over time, and in different environments.

Heredity is the concept that the characteristics of an individual plant or animal in a population could be passed down through the generations. Offspring look more like their parents (**Figure 1**). People learned that some heritable characteristics (such as the size or colour of fruit) varied between individuals, and that they could select or breed crops and animals for the most favorable traits. Knowledge of these hereditary properties has been of significant value in the history of human development. In the past, humans could only manipulate and select from naturally existing combinations of genes. More recently, with the discovery of the substance and nature of genetic material, DNA, we can now identify, clone, and create novel, better combinations of genes that will serve our goals. Understanding the mechanisms of genetics is fundamental to using it wisely and for the betterment of all.

Prior to **Mendel** (1865) heredity was considered to be of a "**blended inheritance**" but his work demonstrated that inheritance was particulate in nature (**particulate inheritance**). We now call these "particles" **genes** and their different forms, **alleles**. By the early 1900's, biochemists had isolated hundreds of different chemicals from living cells, but which of these was the genetic material? Proteins seemed like promising candidates, since they were abundant, diverse, and complex molecules. However, a few key experiments demonstrated that DNA, rather than protein, is the genetic material.

1. GRIFFITH'S TRANSFORMATION EXPERIMENT (1928)

Microbiologists identified two strains of the bacterium *Streptococcus pneumoniae*. The R-strain produced rough colonies on a bacterial plate, while the other S-strain was smooth (**Figure 2**). More importantly, the S-strain bacteria caused fatal infections when injected into mice, while the R-strain did not (**Figure 3**). Neither did "heat-treated" S-strain cells. **Griffith** in 1929 noticed that upon mixing "heat-treated" S-strain cells together with some R-type bacteria (neither should kill the mice), the mice died and there were S-strain, pathogenic cells recoverable. Thus, some non-living component from the S-type strains contained genetic information that could be transferred to and **transform** the living R-type strain cells into S-type cells.

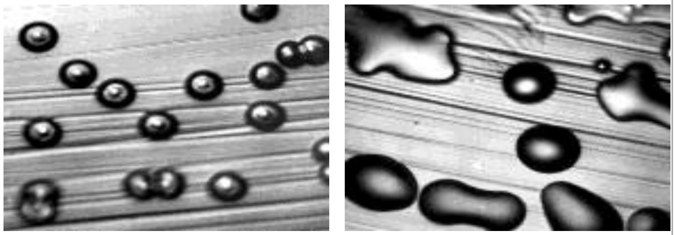

Figure 2.
Colonies of Rough (top) and Smooth (bottom) strains of *S. pneumoniae*.
(J. Exp.Med.98:21, 1953-R. Austrian-Pending)

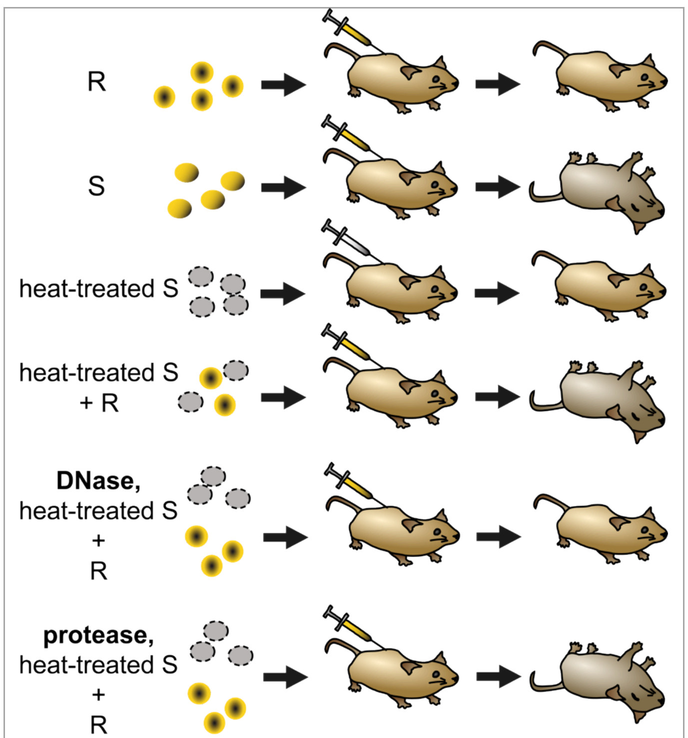

Figure 3.
Experiments of Griffith and of Avery, MacLeod and McCarty. R strains of *S. pneumoniae* do not cause lethality. However, DNA-containing extracts from pathogenic S strains are sufficient to make R strains pathogenic.
(Original-Deyholos- CC BY-NC 3.0)

2. AVERY, MACLEOD AND MCCARTY'S EXPERIMENT (1944)

What kind of molecule from within the S-type cells was responsible for the transformation? To answer this, researchers named **Avery, MacLeod and McCarty** separated the S-type cells into various components, such as proteins, polysaccharides, lipids, and nucleic acids. Only the nucleic acids from S-type cells were able to make the R-strains smooth and fatal. Furthermore, when cellular extracts of S-type cells were treated with **DNase** (an enzyme that digests DNA), the transformation ability was lost. The researchers therefore concluded that DNA was the genetic material, which in this case controlled the appearance (smooth or rough) and pathogenicity of the bacteria.

3. HERSHEY AND CHASE'S EXPERIMENT (1952)

Further evidence that DNA is the genetic material came from experiments conducted by **Hershey and Chase**. These researchers studied the transmission of genetic information in a virus called the T2 **bacteriophage**, which used *Escherichia coli* as its host bacterium (**Figure 4**).

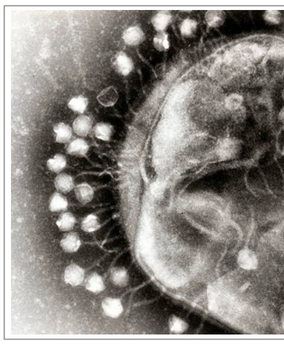

Figure 4.
Electronmicrograph of T2 bacteriophage on surface of E. coli.
(Wikipedia- Dr Graham Beards- CC BY-SA 3.0)

Like all viruses, T2 hijacks the cellular machinery of its host to manufacture more viruses. The T2 phage itself only contains both protein and DNA, but no other class of potential genetic material. To determine which of these two types of molecules contained the genetic blueprint for the virus, Hershey and Chase grew viral cultures in the presence of radioactive isotopes of either phosphorus (^{32}**P**) or sulphur (^{35}**S**). The phage incorporated these isotopes into their DNA and proteins, respectively (**Figure 5**). The researchers then infected *E. coli* with the radiolabeled viruses, and looked to see whether ^{32}P or ^{35}S entered the bacteria. After ensuring that all viruses had been removed from the surface of the cells, the researchers observed that infection with ^{32}P labeled viruses (but not the ^{35}S labeled viruses) resulted in radioactive bacteria. This demonstrated that DNA was the material that contained genetic instructions.

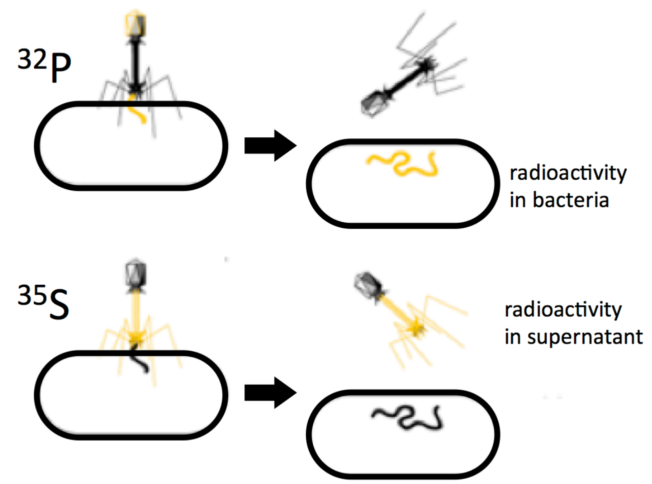

Figure 5.
When ^{32}P-labeled phage infects *E. coli*, radioactivity is found only in the bacteria, after the phage are removed by agitation and centrifugation. In contrast, after infection with ^{35}S-labeled phage, radioactivity is found only in the supernatant that remains after the bacteria are removed. (Original-Deyholos- CC BY-NC 3.0)

4. RNA AND PROTEIN

While DNA is the genetic material for the vast majority of organisms, there are some viruses that use **RNA** as their genetic material. These viruses can be either single or double stranded. Examples include SARS, influenza, hepatitis C and polio, as well as the retroviruses like HIV-AIDS. Typically there is DNA used at some stage in their life cycle to replicate their RNA genome.

Also, the **prion** protein is an infectious agent that transmits characteristics via only a protein (no nucleic acid present). Prions infect by transmitting a mis-folded protein state from one aberrant protein molecule to a normally folded molecule. These agents are responsible for Bovine Spongiform Encephalopathy (BSE, also known as "mad cow disease") in cattle, Chronic Wasting Disease in deer, Scrapie is sheep and Creutzfeldt–Jakob disease (CJD) in humans. All known prion diseases act by altering the structure of the brain or other neural tissue and all are currently untreatable and ultimately fatal.

SUMMARY:

- Genetics is the scientific study of heredity and the variation of inherted characteristics.
- Heredity is the concept that a trait of an individual can br passed down through generations
- A gene can be defined abstractly as a unit of inheritance.
- The experiments done by Griffitish and Hershey and Chase showed the ability of DNA from bacteria and viruses to transfer genetic information into bacteria demonstrates that DNA is the genetic material and that its universal.
- Some viruses use RNA as their genetic material and can be either single or double stranded.
- Prion is a misfolding protein that transmits its misfolding property to a normal one.

KEY WORDS:

genetics
heredity
Mendel
blending inheritance
particulate inheritance
gene
allele
Griffith
transform
Avery, MacLeod, & McCarty
DNase
Hershey and Chase
bacteriophage
^{35}S
^{32}P
prion

STUDY QUESTIONS:

1) Imagine that astronauts provide you with living samples of multicellular organisms discovered on another planet. These organisms reproduce with a short generation time, but nothing else is known about their genetics.
   a) How could you define laws of heredity for these organisms?
   b) How could you determine what molecules within these organisms contained genetic information?
   c) Would the mechanisms of genetic inheritance likely be similar for all organisms from this planet?
   d) Would the mechanisms of genetic inheritance likely be similar to organisms from earth?

2) It is relatively easy to extract DNA and protein from cells; biochemists had been doing this since at least the 1800's. Why then did Hershey and Chase need to use radioactivity to label DNA and proteins in their experiments?

3) Starting with mice and R and S strains of *S. pneumoniae*, what experiments in addition to those shown in **Figure 3** to demonstrate that DNA is the genetic material?