lecture # 2
What Are Genes?

THAMES

- What are the Function of Genes?
- What is the scientific process - Revisited?
- What was known about genes in 1940s?
- Does the nucleus contain the genetic material?
- What are the properties of the genetic material?
- Griffith/Avery Experiments - DNA as the genetic material?
- Bacteria & Bacterial Genomes
- Macromolecules in Cells
- Transformation is universal phenomenon - Basis of Genetic Engineering - Other bacterial traits
- Animals, Plants
  - 1/29/06 DNA structure
- Gene, DNA, Chromosomes
- Anatomy of a Gene
  - It's in the DNA - Engineering Body Plan & Beyond!
  - Stop 1/31/06

HC70A Winter 2006
Professor Bob Goldberg
FIGURE 15.5
The Central Dogma of gene expression. DNA is transcribed to make mRNA, which is translated to make a protein.
Gene Action Leads to Specific Traits

10.1 Mendel's Results from Monohybrid Crosses

<table>
<thead>
<tr>
<th>DOMINANT × RECESSIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spherical seeds × Wrinkled seeds</td>
</tr>
<tr>
<td>Yellow seeds × Green seeds</td>
</tr>
<tr>
<td>Purple flowers × White flowers</td>
</tr>
<tr>
<td>Inflated pods × Constricted pods</td>
</tr>
<tr>
<td>Green pods × Yellow pods</td>
</tr>
<tr>
<td>Axial flowers × Terminal flowers</td>
</tr>
<tr>
<td>Tall stems × Dwarf stems</td>
</tr>
<tr>
<td>(1 m)</td>
</tr>
</tbody>
</table>

Figure 6-2: The pathway from DNA to protein. The flow of genetic information from DNA to RNA (transcription) and from RNA to protein (translation) occurs in all living cells.

Altering Genes by Mutation Leads to Genetic Variability - Different Forms of Same Gene

How is science carried out?

Observation → Hypothesis → Predictions (if...then)

Experientiation
(Testing Hypothesis)

Results & Analysis of data
(New Observations)

New Predictions

New Experiments & Results

New Conclusions

Conclusions

Verify Reject Modify 
Hypothesis Hypothesis Hypothesis

Scientists look for "what did I miss" & analyze results critically. Hypotheses are rejected - never proved. One question always leads to another.

Not an opinion
What was known about genes prior to 1940s?

1. On chromosomes
2. At specific location on chromosomes
3. Directed formation of specific traits
4. Could mutate - mutations stable
5. Inherited Mendel's laws of heredity
   Probably either protein or nucleic acid (DNA and RNA)

Discrete units replicate
   → Factor

Did not know what the molecule of inheritance was
Hammerling's Grafting Experiment Showing The Nucleus Contains Genetic Material.

**FIGURE 14.2**

Hammerling's *Acetabularia* reciprocal graft experiment. Hammerling grafted a stalk of each species of *Acetabularia* onto the foot of the other species. In each case, the cap that eventually developed was dictated by the nucleus-containing foot rather than by the stalk.

But what **molecule/substance in the nucleus is responsible for the phenotype?**
Briggs and King's nuclear transplant experiment. Two strains of frogs were used that differed from each other in the number of nucleoli their cells possessed. The nucleus was removed from an egg of one strain, either by sucking the egg nucleus into a micropipette or, more simply, by destroying it with ultraviolet light. A nucleus obtained from a differentiated cell of the other strain was then injected into this enucleate egg. The hybrid egg was allowed to develop. One of three results was obtained in individual experiments: (1) no growth occurred, perhaps reflecting damage to the egg cell during the nuclear transplant operation; (2) normal growth and development occurred up to an early embryo stage, but subsequent development was not normal and the embryo did not survive; and (3) normal growth and development occurred, eventually leading to the development of an adult frog. That frog was of the strain that contributed the nucleus and not of the strain that contributed the egg. Only a few experiments gave this third result, but they serve to clearly establish that the nucleus directs frog development.
Frog cloning experiment of the 1950s lead to cloning of mammals today.

Shows that the nucleus contains all genes needed to program all of mammalian development.

But... how was it shown that genes are made of DNA?
What ARE THE PROPERTIES OF A GENE?

1. Replication
2. Stability (Mutations)
3. Universality
   (a) all cells
   (b) all organisms
4. Direct cell function/Phenotype

How SHOULDN'T DNA BE THE Genetic Material?

How Can these Properties Be Tested Experimentally?
What predictions follow from these properties?
GRIFFITH'S Experiment with Pneumonia Bacteria
1927

The First Genetic Engineering Experiment - Except that was not understood for another 50 years!

*Streptococcus pneumoniae* (survived!)
Bacteria are prokaryotic single cell organisms.

Figure 1-21 The three major divisions (domains) of the living world. Note that traditionally the word bacteria has been used to refer to procaryotes in general, but more recently has been redefined to refer to eubacteria specifically. Where there might be ambiguity, we use the term eubacteria when the narrow meaning is intended. The tree is based on comparisons of the nucleotide sequence of a ribosomal RNA subunit in the different species. The lengths of the lines represent the numbers of evolutionary changes that have occurred in this molecule in each lineage (see Figure 1-22).

How show that these creatures are related? Predictions?
A "Typical" Bacterial Cell

- Plasmids: 3,000 - 150,000 bp (1 - 100 genes)
- Chromosome: 500,000 - 5,000,000 bp (500 - 4,500 genes)

**E. coli** DNA = ~14 mm (10^-3 m) in circumference
Small plasmid DNA = 14 nm (10^-6 m) in circumference

Anti-biotic gene = "Vectors" for genetic engineering
**Size Relationships Between Atoms, Molecules, Cells, and Organisms**

**Figure 1-20** Biologists are interested in objects ranging in size from small molecules to the tallest trees. A sampling of biological objects aligned on a logarithmic scale. (a) The DNA double helix has a diameter of about 2 nm. (b) Eight-cell-stage human embryo three days after fertilization, about 200 μm across. (c) A wolf spider, about 15 mm across. (d) Emperor penguins are about 1 m tall. [Part (a) Will and Deni McIntyre. Part (b) Yorgas Nikas/Photo Researchers, Inc. Part (c) Gary Gaugler/Visuals Unlimited, Inc. Part (d) Hugh S. Rose/Visuals Unlimited, Inc.]

\[
\begin{align*}
1 \text{ Å} & = 10^{-10} \text{ m} \\
10 \text{ Å} & = 1 \text{ nm} = 1 \times 10^{-9} \text{ m}
\end{align*}
\]

1 meter = 39.4 inches = 3 feet!
4.4 A Prokaryotic Cell

The bacterium *Pseudomonas aeruginosa* illustrates typical prokaryotic cell structures. The electron micrograph on the left is magnified about 80,000 times. Note the existence of several protective structures external to the plasma membrane.
Bacteria have much less DNA and fewer genes than higher organisms.

Figure 1-38 Genome sizes compared. Genome size is measured in nucleotide pairs of DNA per haploid genome, that is, per single copy of the genome. (The cells of sexually reproducing organisms such as ourselves are generally diploid; they contain two copies of the genome, one inherited from the mother, the other from the father.) Closely related organisms can vary widely in the quantity of DNA in their genomes, even though they contain similar numbers of functionally distinct genes. (Data from W.-H. Li, Molecular Evolution, pp. 380-383. Sunderland, MA: Sinauer, 1997.)

E. coli 4,600,000 bp 4,300 genes
Humans 3,200,000,000 bp 35,000 genes

Note: Human genome is 60x larger than E. coli; but only ~10x larger # genes!!

Humans can gene plants have more DNA than humans?
14.1 Amounts of Genomic DNA Can Be Deceiving

Eukaryotes have more DNA in their genomes than prokaryotes. However, among some eukaryotes—especially plants—there is no apparent relationship between diploid genome size and organism complexity.

![Diagram showing genome sizes and gene numbers for various organisms.]

**FIGURE 19.15**

What the human genome is like. The human genome has an unexpectedly small number of genes, some 30,000. This is not many more than the plant *Arabidopsis*, and only a third more than nematode worms.
### TABLE 1-1 Some Genomes That Have Been Completely Sequenced

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>SPECIAL FEATURES</th>
<th>HABITAT</th>
<th>GENOME SIZE</th>
<th>NUMBER OF GENES</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mycoplasma genitalium</em></td>
<td>smallest genome of any known cell</td>
<td>human genital tract</td>
<td>580</td>
<td>468</td>
</tr>
<tr>
<td><em>Synechocystis sp.</em></td>
<td>photosynthetic, oxygen-generating (cyanobacteria)</td>
<td>lakes and streams</td>
<td>3573</td>
<td>3168</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>causes stomach ulcers and predisposes to stomach cancer</td>
<td>human gut</td>
<td>4629</td>
<td>4289</td>
</tr>
<tr>
<td><em>Helicobacter pylori</em></td>
<td></td>
<td>human stomach</td>
<td>1667</td>
<td>1590</td>
</tr>
<tr>
<td><em>Bacillus subtilis</em></td>
<td>bacterium</td>
<td>soil</td>
<td>4214</td>
<td>4098</td>
</tr>
<tr>
<td><em>Aquifex aeolicus</em></td>
<td>lithotrophic; lives at high temperatures</td>
<td>hydrothermal vents</td>
<td>1551</td>
<td>1544</td>
</tr>
<tr>
<td><em>Mycobacterium tuberculosis</em></td>
<td>causes tuberculosis</td>
<td>human tissues</td>
<td>4447</td>
<td>4402</td>
</tr>
<tr>
<td><em>Treponema pallidum</em></td>
<td>spirochaete; causes syphilis</td>
<td>human tissues</td>
<td>1138</td>
<td>1041</td>
</tr>
<tr>
<td><em>Rickettsia prowazekii</em></td>
<td>bacterium most closely related to mitochondria; causes typhus</td>
<td>lice and humans (infectious disease)</td>
<td>1111</td>
<td>834</td>
</tr>
<tr>
<td><em>Thermotoga maritima</em></td>
<td>organotrophic; lives at high temperatures</td>
<td>hydrothermal vents</td>
<td>1860</td>
<td>1877</td>
</tr>
</tbody>
</table>

### ARCHAEAE

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>SPECIAL FEATURES</th>
<th>HABITAT</th>
<th>GENOME SIZE</th>
<th>NUMBER OF GENES</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Methanococcus jannaschii</em></td>
<td>lithotrophic, anaerobic, methane-producing</td>
<td>hydrothermal vents</td>
<td>1664</td>
<td>1750</td>
</tr>
<tr>
<td><em>Archaeoglobus fulgidus</em></td>
<td>lithotrophic or organotrophic, anaerobic, sulfate-reducing</td>
<td>hydrothermal vents</td>
<td>2178</td>
<td>2493</td>
</tr>
<tr>
<td><em>Aeropyrum pernix</em></td>
<td>aerobic, organotrophic</td>
<td>coastal volcanic</td>
<td>669</td>
<td>2620</td>
</tr>
</tbody>
</table>

### EUCHARITERES

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>SPECIAL FEATURES</th>
<th>HABITAT</th>
<th>GENOME SIZE</th>
<th>NUMBER OF GENES</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Saccharomyces cerevisiae</em></td>
<td>minimal model eucaryote</td>
<td>grape skins, beer</td>
<td>12,069</td>
<td>-6300</td>
</tr>
<tr>
<td>(budding yeast)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Arabidopsis thaliana</em></td>
<td>model organism for flowering plants</td>
<td>soil and air</td>
<td>-142,000</td>
<td>-26,000</td>
</tr>
<tr>
<td>(wall cress)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Caenorhabditis elegans</em></td>
<td>simple animal with perfectly predictable development</td>
<td>soil</td>
<td>-97,000</td>
<td>-19,000</td>
</tr>
<tr>
<td>(nematode worm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Drosophila melanogaster</em></td>
<td>key to the genetics of animal development</td>
<td>rotting fruit</td>
<td>-137,000</td>
<td>-14,000</td>
</tr>
<tr>
<td>(fruit fly)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Homo sapiens</em> (human)</td>
<td>most intensively studied mammal</td>
<td>houses</td>
<td>-3,200,000</td>
<td>-30,000</td>
</tr>
</tbody>
</table>

One of the most exciting areas of biology today!
14.1 A Comparison of Prokaryotic and Eukaryotic Genes and Genomes

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>PROKARYOTES</th>
<th>EUKARYOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genome size (base pairs)</td>
<td>$10^4$-$10^7$</td>
<td>$10^8$-$10^{11}$</td>
</tr>
<tr>
<td>Repeated sequences</td>
<td>Few</td>
<td>Many</td>
</tr>
<tr>
<td>Noncoding DNA within coding sequences</td>
<td>Rare</td>
<td>Common</td>
</tr>
<tr>
<td>Transcription and translation separated in cell</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>DNA segregated within a nucleus</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>DNA bound to proteins</td>
<td>Some</td>
<td>Extensive</td>
</tr>
<tr>
<td>Promoter</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Enhancer/silencer</td>
<td>Rare</td>
<td>Common</td>
</tr>
<tr>
<td>Capping and tailing of mRNA</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>RNA splicing required</td>
<td>Rare</td>
<td>Common</td>
</tr>
<tr>
<td>Number of chromosomes in genome</td>
<td>One</td>
<td>Many</td>
</tr>
</tbody>
</table>

Bacterial genes & genomes differ from those of higher organisms.

Only in details - not overall chemical/DNA features.
**Bacteria are highly diverse creatures**

Table 34.1  Bacteria

<table>
<thead>
<tr>
<th>Major Group</th>
<th>Typical Examples</th>
<th>Key Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ARCHAEA BACTERIA</strong></td>
<td></td>
<td>Bacteria that are not members of the kingdom Eubacteria. Mostly anaerobic with unusual cell walls. Some produce methane. Others reduce sulfur.</td>
</tr>
<tr>
<td>Archaea bacteria</td>
<td>Methanogens, thermophiles, halophiles</td>
<td></td>
</tr>
<tr>
<td>Actinomycetes</td>
<td>Streptomycetes, Actinomycetes</td>
<td></td>
</tr>
<tr>
<td>Chemolithotrophs</td>
<td>Sulfur bacteria, Nitrobacter, Nitrosothermotes</td>
<td></td>
</tr>
<tr>
<td>Cyanobacteria</td>
<td>Anabaena, Nostoc</td>
<td>A form of photosynthetic bacteria common in both marine and freshwater environments. Deeply pigmented; often responsible for &quot;blooms&quot; in polluted waters.</td>
</tr>
<tr>
<td>Enterobacteria</td>
<td>Bacteroidia coli, Salmonella, Vibrio</td>
<td>Gram-negative, rod-shaped bacteria. Do not form spores; usually aerobic heterotrophs; cause many important diseases, including bubonic plague and cholera.</td>
</tr>
<tr>
<td>Gliding and budding bacteria</td>
<td>Myxobacteria, Chondromyces</td>
<td>Gram-negative bacteria. Exhibit gliding motility by secreting slimy polysaccharides over which masses of cells glide; some groups form upright multilecellular structures carrying spores called fruiting bodies.</td>
</tr>
<tr>
<td>Pseudomonads</td>
<td>Pseudomonas</td>
<td>Gram-negative heterotrophic rods with polar flagella. Very common form of soil bacteria; also contain many important plant pathogens.</td>
</tr>
<tr>
<td>Rickettsia and Chlamydia</td>
<td>Rickettsia, Chlamydia</td>
<td>Small, gram-negative intracellular parasites. Rickettsia life cycle involves both mammals and arthropods such as fleas and ticks; Rickettsia are responsible for many fatal human diseases, including typhus (Rickettsia prowazeki) and Rocky Mountain spotted fever. Chlamydial infections are one of the most common sexually transmitted diseases.</td>
</tr>
<tr>
<td>Spirochete</td>
<td>Treponema</td>
<td>Long, coil-shaped cells. Common in aquatic environments; a parasitic form is responsible for the disease syphilis.</td>
</tr>
</tbody>
</table>
BACTERIA ARE AMONG THE MOST LETHAL ORGANISMS ON THE EARTH!

Table 34.2 Important Human Bacterial Diseases

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen</th>
<th>Vector/Reservoir</th>
<th>Epidemiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthrax</td>
<td>Bacillus anthracis</td>
<td>Animals, including processed skins</td>
<td>Bacterial infection that can be transmitted through contact or ingested. Rare except in sporadic outbreaks. May be fatal.</td>
</tr>
<tr>
<td>Botulism</td>
<td>Clostridium botulinum</td>
<td>Improperly prepared food</td>
<td>Contracted through ingestion or contact with wound. Produces acute toxic poison; can be fatal.</td>
</tr>
<tr>
<td>Chlamydia</td>
<td>Chlamydia trachomatis</td>
<td>Humans, STD</td>
<td>Urogenital infections with possible spread to eyes and respiratory tract. Occurs worldwide; increasingly common over past 20 years.</td>
</tr>
<tr>
<td>Cholera</td>
<td>Vibrio cholerae</td>
<td>Human feces, plankton</td>
<td>Causes severe diarrhoea that can lead to death by dehydration; 50% peak mortality if the disease goes untreated. A major killer in times of crowding and poor sanitation; over 100,000 died in Rwanda in 1994 during a cholera outbreak.</td>
</tr>
<tr>
<td>Dental caries</td>
<td>Streptococcus</td>
<td>Humans</td>
<td>A dense collection of this bacteria on the surface of teeth leads to secretion of acids that destroy minerals in tooth enamel—sugar alone will not cause caries.</td>
</tr>
<tr>
<td>Diphtheria</td>
<td>Corynebacterium diphtheriae</td>
<td>Humans</td>
<td>Acute inflammation and lesions of mucous membranes. Spread through contact with infected individual. Vaccines available.</td>
</tr>
<tr>
<td>Gonorrhoea</td>
<td>Neisseria gonorrhoeae</td>
<td>Humans only</td>
<td>STD, on the increase worldwide. Usually not fatal.</td>
</tr>
<tr>
<td>Hansen’s disease (leprosy)</td>
<td>Mycobacterium leprae</td>
<td>Humans, feral armadillos</td>
<td>Chronic infection of the skin; worldwide incidence about 10-12 million, especially in Southeast Asia. Spread through contact with infected individuals.</td>
</tr>
<tr>
<td>Lyme disease</td>
<td>Borrelia burgdorferi</td>
<td>Ticks, deer, small rodents</td>
<td>Spread through bite of infected tick. Lesion followed by malaise, fever, fatigue, pain, stiff neck, and headache.</td>
</tr>
<tr>
<td>Peptic ulcers</td>
<td>Helicobacter pylori</td>
<td>Humans</td>
<td>Originally thought to be caused by stress or diet, most peptic ulcers now appear to be caused by this bacterium; good news for ulcer sufferers as it can be treated with antibiotics.</td>
</tr>
<tr>
<td>Plague</td>
<td>Yersinia pestis</td>
<td>Fleas of wild rodents: rats and squirrels</td>
<td>Killed 1/4 of the population of Europe in the 14th century; endemic in wild rodent populations of the western U.S. today.</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>Streptococcus pneumonia, Chlamydia</td>
<td>Humans</td>
<td>Acute infection of the lungs, often fatal without treatment.</td>
</tr>
<tr>
<td>Tuberculosis</td>
<td>Mycobacterium tuberculosis</td>
<td>Humans</td>
<td>An acute bacterial infection of the lungs, lymph, and meninges. Its incidence is on the rise, complicated by the development of new strains of the bacteria that are resistant to antibiotics.</td>
</tr>
<tr>
<td>Typhoid fever</td>
<td>Salmonella typhi</td>
<td>Humans</td>
<td>A systemic bacterial disease of worldwide incidence. Less than 500 cases a year are reported in the U.S. The disease is spread through contaminated water or foods (such as improperly washed fruits and vegetables). Vaccines are available for travelers.</td>
</tr>
<tr>
<td>Typhus</td>
<td>Rickettsia typhi</td>
<td>Lice, rat fleas, humans</td>
<td>Historically a major killer in times of crowding and poor sanitation; transmitted from human to human through the bite of infected lice and fleas. Typhus has a peak untreated mortality rate of 70%.</td>
</tr>
</tbody>
</table>

**Potential bioterror weapons!**
FIGURE 15.1
The unraveled chromosome of an *E. coli* bacterium. This complex tangle of DNA represents the full set of assembly instructions for the living organism *E. coli*.
1927!!

**GRIFFITH'S PNEUMONIA BACTERIA EXPERIMENT**

14-2 (a) Encapsulated and (b) nonencapsulated forms of pneumococci. The capsule is made up of polysaccharides deposited outside the cell wall. The encapsulated form, which is resistant to phagocytosis by white blood cells, produces pneumonia; the mutant, nonencapsulated form is harmless.

**What is the basis of avirulence?**

**Streptococcus pneumoniae** - Genome sequenced 2001 2.1Mb 2236 genes

(a) Smooth/Virulent

(b) Rough/Avirulent

Spontaneous Mutation

1927 Griffith Experiment
**Figure 2.2 Griffith’s transformation experiments.** (a) Virulent strain S. pneumoniae bacteria kill their host; (b) avirulent strain R bacteria cannot infect successfully, so the mouse survives; (c) strain S bacteria that are heat-killed can no longer infect; (d) a mixture of strain R and heat-killed strain S bacteria kills the mouse. The killed virulent (S) bacteria have transformed the avirulent (R) bacteria to virulent (S).
LARGE MOLECULES IN CELLS HAVE DIFFERENT STRUCTURES

**MONOMERS**
- Amino acid
  \[ \text{H}_2\text{N}-\text{C}-\text{C}-\text{O}- \]

- Nucleotide
  \[ \text{O} \]

- Monosaccharide
  \[ \text{HO} \]

**POLYMERS**
- Polypeptide
  \[ \text{H} \quad \text{N} \quad \text{C} \quad \text{O} \] + \[ \text{H}_2\text{O} \]

- Nucleic acid
  \[ \text{H}_2\text{O} \] + \[ \text{H}_2\text{O} \]

- Polysaccharide
  \[ \text{HO} \]

**Carbohydrate**

**Chemistry → Biology!**
(What predict it DNA the genetic material?)
**LARGE MOLECULES IN ALL CELLS**

<table>
<thead>
<tr>
<th>Macromolecule</th>
<th>Subunit</th>
<th>Function</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROTEINS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Globular</td>
<td>Amino acids</td>
<td>Catalysis; transport</td>
<td>Hemoglobin</td>
</tr>
<tr>
<td>Structural</td>
<td>Amino acids</td>
<td>Support</td>
<td>Hair; silk</td>
</tr>
<tr>
<td><strong>NUCLEIC ACIDS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DNA</td>
<td>Nucleotides</td>
<td>Encodes genes</td>
<td>Chromosomes</td>
</tr>
<tr>
<td>RNA</td>
<td>Nucleotides</td>
<td>Needed for gene expression</td>
<td>Messenger RNA</td>
</tr>
<tr>
<td><strong>LIPIDS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fats</td>
<td>Glycerol and three fatty acids</td>
<td>Energy storage</td>
<td>Butter; corn oil; soap</td>
</tr>
<tr>
<td>Phospholipids</td>
<td>Glycerol, two fatty acids,</td>
<td>Cell membranes</td>
<td>Lecithin</td>
</tr>
<tr>
<td></td>
<td>phosphate, and polar R groups</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prostaglandins</td>
<td>Five-carbon rings with two</td>
<td>Chemical messengers</td>
<td>Prostaglandin E (PGE)</td>
</tr>
<tr>
<td></td>
<td>nonpolar tails</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steroids</td>
<td>Four fused carbon rings</td>
<td>Membranes; hormones</td>
<td>Cholesterol; estrogen</td>
</tr>
<tr>
<td>Terpenes</td>
<td>Long carbon chains</td>
<td>Pigments; structural</td>
<td>Carotene; rubber</td>
</tr>
<tr>
<td><strong>CARBOHYDRATES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch, glycogen</td>
<td>Glucose</td>
<td>Energy storage</td>
<td>Potatoes</td>
</tr>
<tr>
<td>Cellulose</td>
<td>Glucose</td>
<td>Cell walls</td>
<td>Paper; strings of celery</td>
</tr>
<tr>
<td>Chitin</td>
<td>Modified glucose</td>
<td>Structural support</td>
<td>Crab shells</td>
</tr>
</tbody>
</table>

Which is the transforming principle and the genetic material?

1. What is predicted if DNA is the genetic material?
2. How test hypothesis?
Maclyn McCarty, 93; Helped Unlock the Secrets of DNA

By Thomas H. Maugh II
Times Staff Writer

January 8, 2005

Maclyn McCarty, the last surviving member of the trio of researchers who defied conventional wisdom by proving that our genetic blueprint is encoded in deoxyribonucleic acid — DNA — has died. He was 93.

McCarty died Sunday of congestive heart failure at a hospital in New York City, where he lived.

Surprisingly, the research team did not receive the Nobel Prize for its effort, which Nobel laureate Joshua Lederberg has called "the pivotal discovery of 20th century biology."

For the work laid the foundation for many other researchers who did receive the Nobel, beginning with James Watson and Francis Crick, who deciphered the structure of DNA only nine years after McCarty and his colleagues published their results.

Before McCarty began his work in 1941 with Oswald T. Avery and Colin M. MacLeod, all of whom were at Rockefeller University in New York City (then known as the Rockefeller Institute of Medical Research), most scientists thought genetic information was carried by proteins, long chains composed of at least 20 different amino acids.

DNA, which contained only four distinct chemical compounds called bases, was believed to be too simple to carry the complex information necessary for building even a bacterium, much less a human. Avery, MacLeod and McCarty put the lie to that argument.

The stage was set for their work in 1928 when British microbiologist Frederick Griffith discovered what was then called the "transforming principle." Griffith was studying two closely related strains of the bacterium Streptococcus pneumoniae. One of the strains, called S, killed mice when it infected them. The second strain, called R, did not.

Griffith found that when he mixed chemicals from the S strain with living R bacteria, the treated bacteria became the lethal S strain. Griffith called the chemicals the transforming principle, but we now recognize that he was transferring genes from the S strain to the R strain.

Avery and MacLeod began trying to identify what it was in the mixture of chemicals that produced the change. When MacLeod left Rockefeller in 1941, McCarty started working with Avery to finish solving the puzzle.

Because the rudimentary chemical techniques of the period would not allow them to isolate the transforming principle directly, they took a different approach. First, they took an enzyme that destroyed proteins and added it to the...
transforming principle. The R strains still became S, so proteins clearly did not carry genetic information.

Next, they used enzymes that destroyed ribonucleic acid — RNA — which a few scientists thought might carry genetic information. Again, R strains still became S. Eliminating proteins and RNA took more than a decade and led them to suspect that DNA, the only major component left, was the key molecule.

When McCarty joined the team, he isolated an enzyme that degraded DNA, the first such enzyme known. When they added this enzyme to the transforming principle, all its activity was destroyed. Hence, DNA carries genetic information. The three finally published their conclusion in February 1944, opening the door to the age of biotechnology.

McCarty was born June 9, 1911, in South Bend, Ind., where his father was an executive with the Studebaker Corp. The family moved frequently because of his father's job, and McCarty later attributed his inquiring mind to the diversity of people and places he encountered.

He studied biochemistry at Stanford, then got his medical degree at Johns Hopkins University, specializing in pediatrics. New antibiotics were coming into use during this period, and McCarty was one of the first physicians to save a child from a usually lethal streptococcus infection using the newly developed sulfonamide drugs. The encounter sparked a lifelong interest in infectious agents.

During World War II, he did research with the Naval Medical Research Unit at Rockefeller while completing his studies of the transforming principle.

He remained at Rockefeller the rest of his life, spending most of his time studying the structure of the streptococci bacteria that cause rheumatic fever. Over the next four decades, his team identified virtually every component in the cell wall structure of the streptococci, making them one of the best-characterized disease-causing bacteria.

He received a number of major awards over the years for his research and his organizational efforts in monitoring and responding to infectious diseases internationally.

In 1994, long after Avery and MacLeod died, McCarty finally received the Albert Lasker Award for Special Achievement in Medical Science, a prize some call the American Nobel.

McCarty recounted his research in his 1985 book, "The Transforming Principle: Discovering That Genes Are Made of DNA." He did not particularly lament that the team had not received a Nobel for its work, but he expressed disappointment that Watson and Crick had not cited the work in their 1953 paper describing DNA's structure.

In 2003, Watson formally apologized for the omission. In his defense, Watson noted that by 1953, the idea of DNA carrying genetic information had become so widely accepted that it didn't seem necessary to acknowledge the earlier work.

McCarty is survived by his second wife, the former Marjorie Fried; sons Richard E. and Colin Avery; daughter Dale Dinunzio; eight grandchildren and five great-grandchildren.

If you want other stories on this topic, search the Archives at latimes.com/archives.

TMSReprints

Article licensing and reprint options

Copyright 2005 Los Angeles Times
First "Naked" DNA Transformation or Genetic Engineering Experiment!

Avery, McCleod, & MacCarty Experiment showing DNA is the genetic material.

Message: The demonstration that DNA is the transforming principle was the first demonstration that genes are composed of DNA.

Figure 8-2 Demonstration that DNA is the transforming agent. DNA is the only agent that produces smooth (S) colonies when added to live rough (R) cells.

DNA from dead smooth/virulent cells can transform live/avirulent cells → live virulent cells.

DNA taken up by live smooth cells & causes transformation.
**Hypothesis?**

**Predictions?**

**Experiment to test!**

---

**Figure 4-2** Experimental demonstration that DNA is the genetic material. These experiments, carried out in the 1940s, showed that adding purified DNA to a bacterium changed its properties and that this change was faithfully passed on to subsequent generations. Two closely related strains of the bacterium *Streptococcus pneumoniae* differ from each other in both their appearance under the microscope and their pathogenicity. One strain appears smooth (S) and causes death when injected into mice, and the other appears rough (R) and is nonlethal.

(A) This experiment shows that a substance present in the S strain can change (or transform) the R strain into the S strain and that this change is inherited by subsequent generations of bacteria. (B) This experiment, in which the R strain has been incubated with various classes of biological molecules obtained from the S strain, identifies the substance as DNA.

---

**Conclusion:** Molecules that can carry heritable information are present in S strain cells.

---

**Conclusion:** The molecule that carries the heritable information is DNA.
How did Avery's experiment verify the hypothesis that DNA is the gene?

<table>
<thead>
<tr>
<th>Predictions</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>Yes</td>
</tr>
<tr>
<td>Phenotype</td>
<td>Yes</td>
</tr>
<tr>
<td>Stable</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Cell Processes
- 5 DNA Taken up by R cells
- 5 "gene"
- 5 RNA
- 5 "protein"

Transformation used as a genetic engineering process to present day!

Origin of term from Griffith's 1920's experiment!

Transformation? Ability of a cell phenotype to be changed/transformed by DNA!
Figure 20-3 Microorganisms that normally inhabit the human body. All of the microorganisms listed here—usually harmoniously—live on the surfaces and in the interiors of human bodies. Contact between them, normally known as yeast, is a fungus that lives on the skin and in the mouth and vagina. Candida, of course, is a popular yeast, not a probiotic. (Cath Leasing/Art Resource)
What are Antibiotics?

Figure 25-8 Antibiotic targets. Despite the large number of antibiotics available, they have a narrow range of targets, which are highlighted in yellow. A few representative antibiotics in each class are listed. All antibiotics used to treat human infections fall into one of these categories. The vast majority inhibit either bacterial protein synthesis or bacterial cell wall synthesis.

Figure 20-5 How does it work? A. Every antibiotic has a distinctive way of preventing bacteria from reproducing. B. Bacteria have different ways of resisting the effects of antibiotics.

Antibiotic Resistance isEncoded by Gene on Extra Chromosomal DNA called Plasmids

Made by Fungi and other Bacteria!
The First Genetic Engineering Experiment used Antibiotic Resistance

Antibiotic R DNA + Antibiotic S Cells

Transformation → Antibiotic R Cells

Stanley Cohen & Herb Boyer → 1973

How show DNA Genetic Material?
Can higher organisms be transformed? Genetically engineered?

Recall Glo Fish Experiment!
- Glo Fly
- Glo Mouse
- Glo Plant
- Glo Monkey

DNA → Specific Trait → Replicates
THE MAKING OF A NIFTY MOUSE!

**DNA** → **Growth Hormone** → **Nifty Mouse Phenotype**

**Yo! It's all in the DNA**
CAN PLANTS BE GENETICALLY ENGINEERED OR TRANSFORMED WITH DNA?

Engineering Plants With Novel Genes

Switch Protein Coding Region

Novel Fusion Gene

Gene Inserted Into Ti Plasmid

Agrobacterium Containing Plasmid

Agrobacterium Transfers Ti Plasmid Into Plant Chromosome

Nucleus

Cytoplasm

Regenerate Plants

Novel Crops New Traits

Transgenic Plant

Basic Research How Do Genes Work?
Genetic Engineering For Insect Resistance

Insect Sensitive

Insect Resistant

Bacteria → Insect → Gene/DNA → Plant Cells → Plant

DNA is the genetic material of all organisms

Bacteria → Animals + Plants
DEMONSTRATIONS

Bacteria "Cloning"

Gel Electrophoresis
**Genetic Engineering/Transformation Involves**
**Incorporating Engineered DNA or Genes Into Different Organisms**

**Engineered Gene**
- **MUST**
  1. Enter Target Cell
  2. Use Target Cell Machinery Enzymes to become Part of Chromosome
  3. Replicate with Target Cell Chromosome
  4. Use Target Cell Protein Synthesis Machinery to Make a New Protein → **Phenotype**

**Engineered Gene Can Be**
- 1. From Same Organism
- 2. From Different Organism
- 3. From a Combination of Organisms Stitched Together by Genetic Engineering

**Gene Engineering Shows That Gene Processes Are Universal!**

*Just like the GlobGene Experiments!!!*
Genetic Engineering does not involve any "Hocus Pocus!"

It's all in the DNA & cell processes - activate in "organic" biology.
What are genes?

Electron micrograph of DNA (green arrow) being transcribed into RNA (red arrow). [O. L. Miller, Jr., and Barbara R. Beatty, Oak Ridge National Laboratory.]

Visualization of a gene in action

What is this?

What are these?

How far?
What is a Gene?

The \( \beta \)-globin Gene

Blood protein carries oxygen to all cells from lungs \( \rightarrow \) energy

A gene is a unique sequence of nucleotides specifying a function

SEQUENCE \( \rightarrow \) FUNCTION

Relative to coding or sense strand of gene
Genes ≠ Genomes Differ Because the Sequence of DNA Differ

DNA Sequence
Beginninχ → End
5' → 3' → Biological Uniqueness

If you know the DNA sequence, you can engineer Anything! Even make new genes & genomes!
DNA and Genes Consist of Nucleotides Joined by Bonds

Figure 4-3 DNA and its building blocks. DNA is made of four types of nucleotides, which are linked covalently into a polynucleotide chain (a DNA strand) with a sugar-phosphate backbone from which the bases (A, C, G, and T) extend. A DNA molecule is composed of two DNA strands held together by hydrogen bonds between the paired bases. The arrowheads at the ends of the DNA strands indicate the polarities of the two strands, which run antiparallel to each other in the DNA molecule. In the diagram at the bottom left of the figure, the DNA molecule is shown straightened out; in reality, it is twisted into a double helix, as shown on the right. For details, see Figure 4-5.

1. A nucleotide = sugar + base + phosphate
2. Nucleotides are linked in order 5'→3' by phosphodiester bonds
Numbering the carbon atoms in a nucleotide. The carbon atoms in the sugar of the nucleotide are numbered 1' to 5', proceeding clockwise from the oxygen atom. The "prime" symbol (') indicates that the carbon belongs to the sugar rather than the base.

5'p
Beginning →

3'OH
End →

Based on what is bonded to sugar
The sugar is the hub!!

Order of DNA defined by nucleotide → DNA sequence → biology
NUCLEOTIDES ARE JOINED BY PHOSPHODIESTER BONDS

FIGURE 14.8
A phosphodiester bond.

The order is specified by the nucleotides which join 5'->3'.

The 3' order is defined by sugars. It is specified by bases.

Basis of all genetics and genetic engineering. Order = Biology.
Figure 3.1 A single strand of DNA composed of four nucleotides.

The four bases of DNA:
- G = Guanine
- T = Thymine
- A = Adenine
- C = Cytosine

Figure 14.8 A phosphodiester bond.

ORDER IS MAINTAINED DURING REPLICATION

ORDER IS ESTABLISHED

UNIQUE BIOLOGY!!

Basis of a cell generating the same cell!

U replaces T in RNA
Ribose replaces deoxyribose
There are four nucleotides in DNA.

**Purine nucleotides**
- Deoxyadenosine 5'-phosphate (dAMP)
  - Nitrogen base (adenine, A)
- Deoxyguanosine 5'-phosphate (dGMP)
  - Nitrogen base (guanine, G)

**Pyrimidine nucleotides**
- Deoxycytidine 5'-phosphate (dCMP)
  - Nitrogen base (cytosine, C)
- Deoxythymidine 5'-phosphate (dTMP)
  - Nitrogen base (thymine, T)

Figure 8-4 Chemical structure of the four nucleotides (two with purine bases and two with pyrimidine bases) that are the fundamental building blocks of DNA. The sugar is called deoxyribose because it is a variation of a common sugar, ribose, that has one more oxygen atom.

Chemistry → Biology
Know order of bases → Do anything!
Purines = Pyrimidines in DNA
Chargaff's Rules

\[ A = T \]
\[ G = C \]

In DNA, the amount of purines (A + G)...

...is always equal to the amount of pyrimidines (T + C).

11.5 Chargaff's Rule
The total abundances of purines and pyrimidines are equal in DNA.

<table>
<thead>
<tr>
<th>DNA ORIGIN</th>
<th>AMOUNT OF BASE (PERCENTAGE OF TOTAL DNA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Human (Homo sapiens)</td>
<td>31.0</td>
</tr>
<tr>
<td>Corn (Zea mays)</td>
<td>25.6</td>
</tr>
<tr>
<td>Fruit fly</td>
<td>27.3</td>
</tr>
<tr>
<td>(Drosophila melanogaster)</td>
<td></td>
</tr>
<tr>
<td>Bacterium (Escherichia coli)</td>
<td>26.1</td>
</tr>
</tbody>
</table>

What would you predict for a single strand DNA?
DNA is a double helix of two complementary chains of DNA wound around each other.

1. Complementary strands
2. $A = T$ and $G = C$ (H-bonds)
3. Sequence of strands differs
4. Bases to interior
5. Phosphate/sugar backbone
6. Strands in opposite direction only way chains fit together

**SEQUENCE OF ONE CHAIN AUTOMATICALLY SPECIFIES SEQUENCE OF COMPLEMENTARY CHAIN**

WATSON & CRICK 1953

*ONLY WAY MOLECULE "FITS" TOGETHER!*
Properties of DNA

1. Four different nucleotides
2. Nucleotides linked by phosphodiester bonds
3. Nucleotides linked in order 5'-3'
4. Two chains complementary in antiparallel direction
5. Bases in interior stacked & bonded by H-bonds - complementary "rungs" on "ladder"
6. Backbone - sugar/phosphate bonds
7. No constraint on sequence \( 4^7 = 16 \) # Sequences
8. DNA has dimensions: 20Å diameter
   3.4Å/6p
   106p/turn

Order = Biology

From X-Ray diffraction picture
The Double Helix

(a) The blue bands represent the two sugar-phosphate chains.

(b) Pairs of bases form horizontal connections between the chains.

(c) The two chains run in opposite directions.

---

3.4 nm

Minor groove

Hydrogen

Major groove

Phosphorus

Carbon in sugar-phosphate "backbone"

Oxygen

Bases

---

READ BOOK/TEXT BY SAME NAME!
A chromosome contains one (or two!) continuous DNA molecule.

DNA in higher organisms is linear! DNA in bacteria is circular!
The circular E. coli chromosome: one DNA circle.

Figure 1–30 The genome of E. coli.
(A) A cluster of E. coli cells. (B) A diagram of the E. coli genome of 4,639,221 nucleotide pairs (for E. coli strain K-12).

The diagram is circular because the DNA of E. coli, like that of other procaryotes, forms a single, closed loop. Protein-coding genes are shown as yellow or orange bars, depending on the DNA strand from which they are transcribed; genes encoding only RNA molecules are indicated by green arrows. Some genes are transcribed from one strand of the DNA double helix (in a clockwise direction in this diagram), others from the other strand (counterclockwise). (A, courtesy of Tony Brain and the Science Photo Library; B, after F. R. Blattner et al., Science 277:1453–1462, 1997. © AAAS.)
**A Chromosome Contains Many Genes That Reside at Specific Positions and Have Unique Functions**

Because DNA consists of two strands, genes can be transcribed from either strand, but only one/gene!

---

How do you know when one gene starts and the other ends?
Genes Reside at Specific Positions or loci

Gene Position = locus = unique DNA sequence
Genes reside at specific locations.

Linear DNA
How known?

Note bands - what are those?

How known gene positions? Chromosome #?
**Organization of Genes on Human Chromosome 22**

(A) Human chromosome 22—$48 \times 10^6$ nucleotide pairs of DNA

- Heterochromatin

(B) 10% of chromosome arm ~40 genes

- Gene 1

(C) 1% of chromosome containing 4 genes

- Gene 2
- Gene 3
- Gene 4

(D) Structural
- Switch

- One gene of $3.4 \times 10^4$ nucleotides

- Regulatory DNA sequences

- Exon
- Intron

- Gene expression

- Protein
- Folded protein

Chromosome 22, a "small" one!

One large gene!

Genes are defined/precise regions of DNA

Genes act as individual units.

How are they known? Genetic Engineering, Anti-R

54%
A Chromosome Contains Many Genes

DNA Helix

Gene 1 ORF1
Gene 2 ORF2
Gene 3...

Untwisted View of DNA

mRNA1
mRNA2
mRNA3...

Protein 1
Protein 2
Protein 3...

Central Dogma
Genes → Functions in Cells via Proteins
Cells Replicate and Stay the Same via DNA Replication

Notice - Each gene, mRNA, and protein has a unique order/sequence of monomeric units

Collinearity between gene sequence and protein sequence

Very Important Concept
A Simple Gene = A Double Helix

Gene X

Beginnings: 5' END

Ending: 3' END

TATAAT

Start switch or promoter

AGCTCGAACC

Sense strand

Function: genetic code

Transcribed strand

ATTTT

Termination switch

TCGAGCTTTG

Controls when and where a gene becomes active

Unique cells

Start

Transcription

pAGCUCGAAAC

5' end

mRNA X

3' end

End

Transcription

Complementary to transcribed strand = template for RNA

NOTICE! Specific sequences specify beginning and end of gene to control its activity!

Notice: mRNA sequence = sequence of sense strand
A "Simple" Gene Reviewed

1. **Sense Strand** = Genetic Code
2. **Sense Strand** = 5'→3' Direction (all mRNA Sequences specified 5'→3')
3. **Anti-Sense Strand** = Complement of Sense Strand
   - is Transcribed Strand
4. **mRNA** = Same Sequence as Sense Strand
   - Complementary to Anti-Sense Strand
5. **mRNA** = 5'→3'
6. **Switch** Turns Gene on - NOT TRANSCRIBED BUT UPSTREAM OF CODING REGION

**Genes Function as Independent units - Design Experiment to Show!**

"Everything" Follows the Double Helix & its Rules - Anti-parallel Chains & Complementary Base Pairing!
Control Switches Are Unique DNA Sequences Can Be Cloned!

AND USED TO RE-ENGINEER ORGANISMS!! Switches ACT Independently of Gene!!

FIGURE 3.13 Enhancers and transcription factors in eukaryotic cells. A schematic diagram of the upstream regulatory region for a brain specific transcript is provided.

RULE! SEQUENCE → BIOLOGY!!

NO "HOCUS POCUS"

Yo! IT'S IN THE DNA!
Switches control where and when a gene is active -> unique functions -> unique cells!

<table>
<thead>
<tr>
<th>TYPE OF CELL</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red blood cells (erythrocytes)</td>
<td>Transport oxygen and carbon dioxide</td>
</tr>
<tr>
<td>Platelets (cell fragments without nuclei)</td>
<td>Initiate blood clotting</td>
</tr>
<tr>
<td>White blood cells (leukocytes)</td>
<td>Release histamine; may promote the development of T cells</td>
</tr>
<tr>
<td>Basophils</td>
<td>Release histamine when they are damaged</td>
</tr>
<tr>
<td>Eosinophils</td>
<td>Develop into macrophages</td>
</tr>
<tr>
<td>Neutrophils</td>
<td>Phagocytize antibody-coated pathogens</td>
</tr>
<tr>
<td>Mast cells</td>
<td>Release histamine when they are damaged</td>
</tr>
<tr>
<td>Monocytes</td>
<td>Present antigens to T cells</td>
</tr>
<tr>
<td>Macrophages</td>
<td>Regulate and digest microorganisms; activate T cells</td>
</tr>
<tr>
<td>Dendritic cells</td>
<td>Differentiate to form antibody-producing cells and memory cells</td>
</tr>
<tr>
<td>B cells</td>
<td>Regulate activities of other white blood cells</td>
</tr>
<tr>
<td>Plasma cells</td>
<td>Attack and lyse virus-infected or cancerous body cells</td>
</tr>
</tbody>
</table>

19.2 Blood Cells
Pluripotent stem cells in the bone marrow can differentiate into red blood cells, platelets, and the various types of white blood cells.

Accessory Organs:
- Salivary glands
- Liver
- Gallbladder
- Pancreas
- Ascending colon
- Cecum
- Esophagus
- Stomach
- Large intestine
- Small intestine
- Descending colon
- Rectum
- Anus

Insulin Gene
THE GENE AND SWITCHES ARE UNIQUE DNA SEQUENCES

They can be cloned as "Shuffled" & Engineered

1. Creating [new] genes that have no counterparts in nature → Genetic Engineering

2. These new genes can be transcribed in new cell types (switch change) &/or organisms &/or both (e.g., human genes in plant leaves)

   human gene → plant red switch

3. All genes are regulated & controlled by switches. The Genome Projects reveal both the genes & the switches & wiring together of all switches in gene

   Program of life from birth to death

Yo! It's in the sequences!!
An Eye of a Fly Can be Produced at Other Places on the Fly's Body by Genetic Engineering

Can use switches to engineer where, when gene active in an organism.  

1. Control gene: activate switches of other genes.  

2. These genes can specify proteins that tell cells to develop into complex organs (e.g., eye).  

18-25 The red-eyed fruit fly at the right is the offspring of the brown-eyed fly at the left. Drosophila transposons bearing a gene for red eyes were injected into the brown-eyed fly when it was an early embryo. Transposons with the gene for red eyes were incorporated into chromosomes of the cells that ultimately formed its gametes. The gene for red eyes was therefore passed on to its offspring.  

Use the appropriate switch with a master control gene that switches on other switches to activate genes needed to make an eye!  

Another example is the Sky male gene; it is a control gene that activates other genes.
What Happens if Switch Changed?
**New Gene, Old Gene**

My development is beginning.

This is the ultimate.

And so the ultimate and so the ultimate. And so the ultimate and so the ultimate. And so the ultimate and so the ultimate. And so the ultimate and so the ultimate.

Keith

**Fig. 2** GAL4 drives expression of GAL4 activity in different body parts. A. Organogenesis of an adult head in which both eyes mediate development. (A) Correlation of eye migration and eye structure. (B) Dissected mouthparts show an apparatus for the taste of food.

**Discussion**

Does this lend to organ growth in culture? Transplants? Shows function of organogenetic activity is a function of the development of the eye. The eye is a development of the eye.

**References**

**SCIENCE** Vol. 267, 24 MARCH 1995
CLONING AN ANIMAL FROM A DIFFERENTIATED CELL
NUCLEUS SHOWS THAT GENE SWITCHES CONTAIN...

What is Hypothesis being tested?

The Logic for all Gene is contained in the genome!

Experiment?

Skin cells express specific gene due to their skin cell switches

Development of an organism from a fertilized egg requires all switches to work at correct times to allow normal development.

If the logic of how switches are connected is understood, no life can be programmed!
100 years into the future

1. If the entire human genome is sequenced?
2. If the function/proteins of all genes are known
3. If all the switches are identified & how they go on & off from birth to death
4. If we understand how genes are choreographed & all the sequences that program them

What does the future hold?
We will know at the DNA level what biological information programs life to death!
What does this mean for the future of humanity?

Remember - Mendel's laws were only rediscovered 100 years ago & look what we can do & know!
What is Natural?
How Far Do We Go?