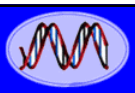

DNA
Genetic Code of Life


Entire Genetic Code
of a Bacteria


DNA Fingerprinting


Cloning: Ethical Issues
and Future Consequences


Plants of Tomorrow

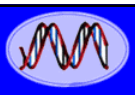
HC70A, SAS70A, & PLSS599
Winter 2022
Genetic Engineering in Medicine, Agriculture, and Law

Professors Bob Goldberg, John Harada, & Channapatna Prakash

Lecture 3
What Are Genes & How Do They Work: Part One

UCLA TUSKEGEE UNIVERSITY UCDAVIS UNIVERSITY OF CALIFORNIA

1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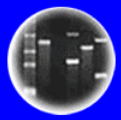
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THEMES
Gene Structure & Function
Part One

- What is the Function of a Gene?
- What are the Properties of Genes?
- How Was DNA Discovered?
- What is the Evidence That DNA is the Genetic Material (Griffith and Avery Experiments)?
- Is Transformation Universal?
- What is the Structure of DNA?
- What is the Structure of a Chromosome?
- What is the Colinearity Between Genes & Proteins (how does DNA→protein)?
- How Do We Know That Genes Function Independently of One Another?
- What is the Anatomy of a Gene?
- How Do Switches Work to Control Gene Activity?
- What Are the Possibilities For Manipulating Genes in the Future?

2

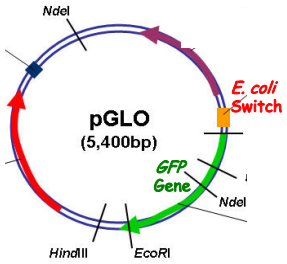
Understanding Genetic Engineering

Requires a Basic Understanding of Genes And How They Work!!!!!!!

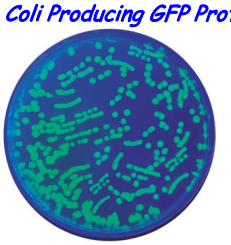
3

What Are the DNA Conceptual Implications of Generating an E. coli Cell Producing GFP Protein?

pGLO Plasmid DNA

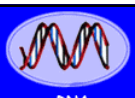


E. Coli Producing GFP Protein



1. DNA Replicates
2. DNA Directs the Cell to Produce a Specific Protein & Express a New Trait
3. DNA is Stable From Cell Generation to Generation – i.e. Cells Derived From the Original Transformed E. Coli Express the *GFP* Gene
4. The *E. coli GFP* Gene Transformation Experiment Shows Directly *That DNA is the Genetic Material!*

4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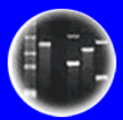
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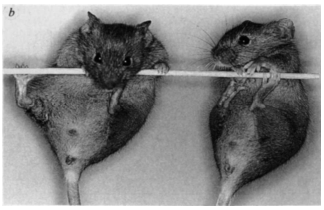
Other Experiments We Discussed Showing That DNA is the Genetic Material



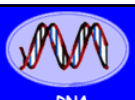
May 20, 2010

Researchers Say They Created a 'Synthetic Cell'

By NICHOLAS WADE

The genome pioneer J. Craig Venter has taken another step in his quest to create synthetic life, by synthesizing an

5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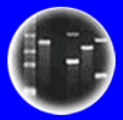
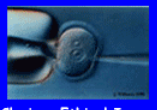

DNA Fingerprinting


Cloning: Ethical Issues
and Future Consequences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What Were Considered the Properties of a Gene BEFORE It Was Known That DNA Was the Genetic Material – In the 1920s to 1940s?

1. Replication – Transmitted With Chromosomes
2. Stability (Mutations)
3. Universality
   a) All Cells
   b) All Organisms
4. Direct Cell Function/Phenotype

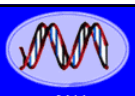
For First Half of 20th Century Proteins Were Considered the Genetic Material

- How Can These Properties Be Tested Experimentally?
- What Predictions Follow From These Properties?

If DNA is the Genetic Material, THEN What……?

How Was DNA Shown to be the Genetic Material?

6



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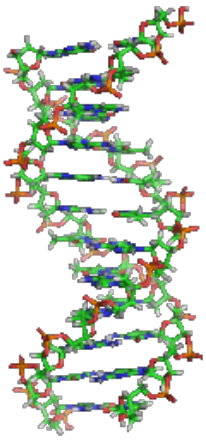

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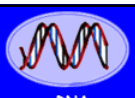

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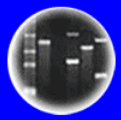

DNA Fingerprinting

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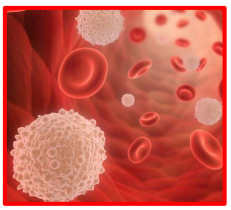
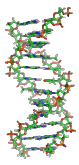
Frederick Miescher Discovered DNA in the Nuclei of White Blood Cells in 1869

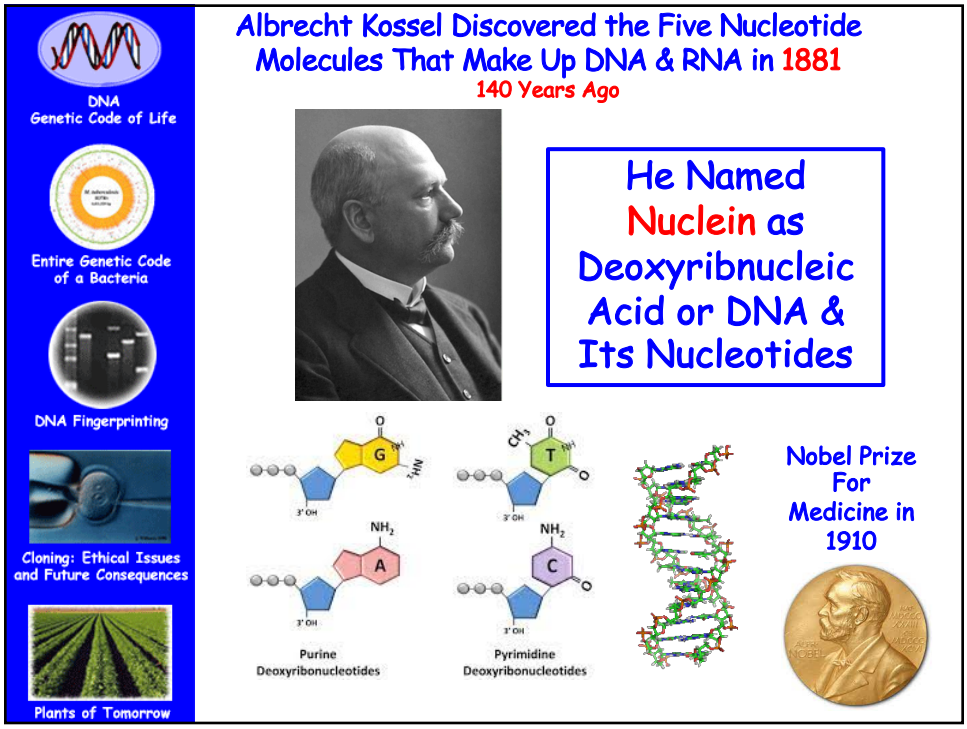
150 Years Ago





But…..The Function of DNA Was Not Understood Until 75 years Later in 1944!!!

8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Albrecht Kossel Discovered the Five Nucleotide Molecules That Make Up DNA & RNA in 1881
140 Years Ago
He Named Nuclein as Deoxyribnucleic Acid or DNA & Its Nucleotides
Purine Deoxyribonucleotides
Pyrimidine Deoxyribonucleotides
Nobel Prize For Medicine in 1910

9


Evidence That DNA Is the Genetic Material Starts With Pneumonia
TO STOP SPREAD OF
INFLUENZA
STAY AT HOME
Player Pianos
FIGHT THE 'FLU'
Rigid Quarantine Rules Established
YOU ARE ASKED TO AID IN ENFORCING THEM
Epidemic Closing Order Is Sweeping
Spanish Flu (H1N1) Killed 500 million People World-Wide from 1918 to 1920
& 675,000 in the US Most From Secondary Bacterial Infections
No Vaccines or Antibiotics!!
Bacterial Pneumonia Caused Most Deaths in 1918 Influenza Pandemic
INFLUENZA
PNEUMONIA
YOU MUST DO THE SAME
GO HOME AND GO TO BED UNTIL YOU ARE WELL
HELP US TO KEEP CHICAGO THE HEALTHIEST CITY IN THE WORLD
The Washington Times
Gauze Mask to Halt Spread of Plague
Streptococcus pneumoniae

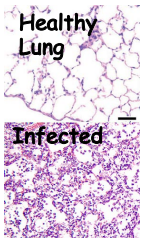
10

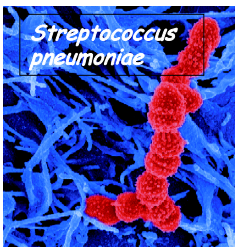
11

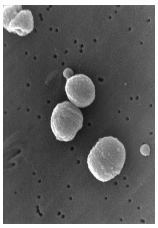
Frederick Griffith & The Transforming Principle

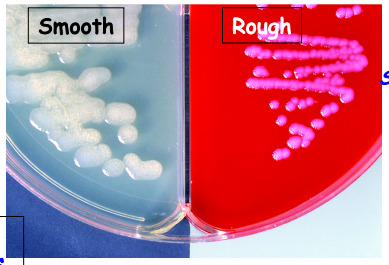
The First Genetic Engineering Experiment (unintentional!)

1879-1941









Note: Diffferent Strains of *Streptococcus pneumoniae* Exist in Nature

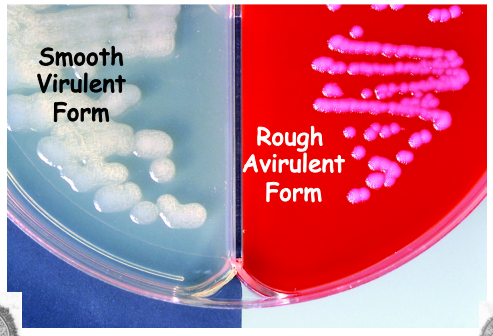
Type I, II, etc. Taken From Patients

Invented the Word "Transformation"
Not Understood For Another 50 Years

12

Griffith - J. Hygiene, 1928

Smoot Virulent Bacteria Can Mutate To Rough Avirulent Bacteria & Vice Versa!

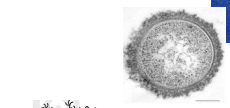


Spontaneous Mutations
Always Retain the Strain Type

SI to RI

Never SI to RII

As Too Many Genes Are Involved!



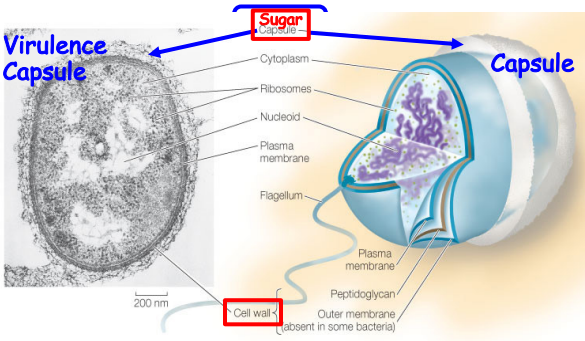
13

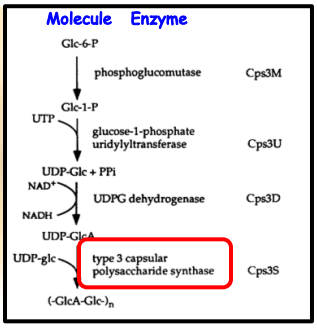
Streptococcus pneumoniae

Flash Forward to 2021!

50,000 Deaths/Year in the USA

Virulence Capsule Biosynthesis





J. Exp. Med. 181, 973, 1995

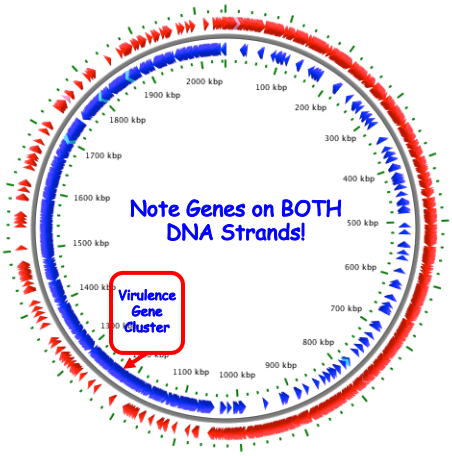
Streptococcus Strains Depend On the Sugar Type in the Capsule - Which is a Product Of MANY Genes!

The Sugar Capsule Protects the Bacteria From Mammalian Host Antibodies

Capsule = Virulence No Capsule = Avirulence

14

Streptococcus pneumoniae Genome Has Been Sequenced!



2,160,837 bp and 2,236 Genes

At Least 13 Genes Specify Capsule Formation

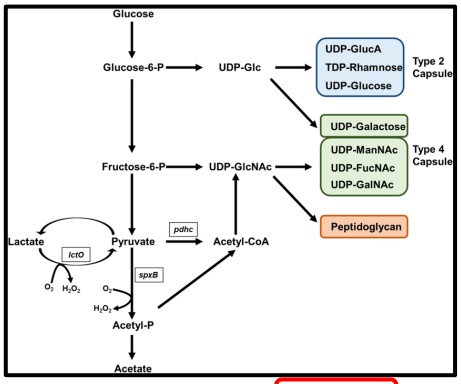
What Happens If One of These Genes Is Mutated?

Science 293,498 (2001)

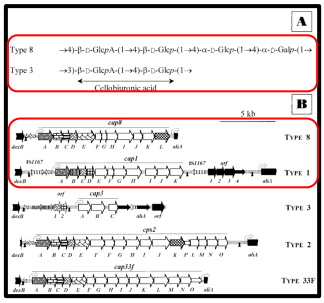
15

Streptococcus pneumoniae Virulence

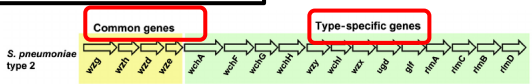
Capsule Sugars – Different Strains Have Different Sugars



Genes Clustered Next to Each Other in the Genome



Different Sugars – Different Sugar Genes!

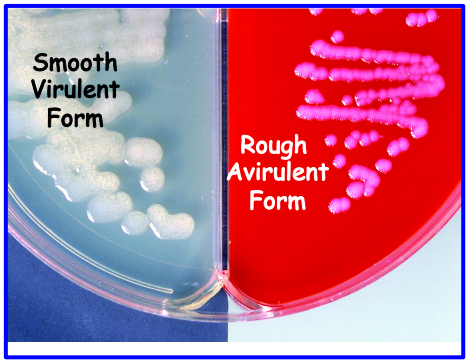


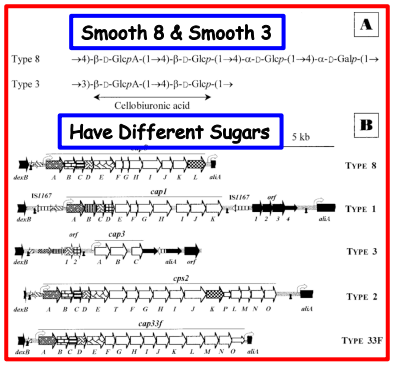
Different Strains Have Different Sugars Encoded By Shared & Distinct Genes Involved in Capsule Sugar Synthesis

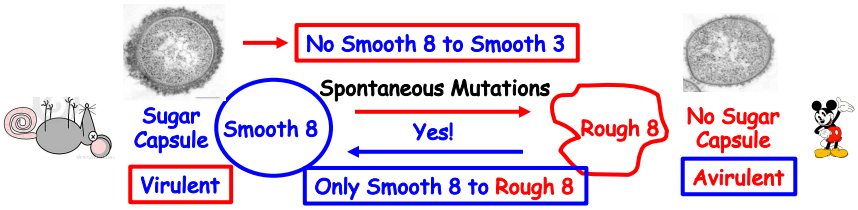
Cannot Mutate From One Strain to Another – Too Many Genes Involved

16

Can Mutate Smooth to Rough But Never Smooth Strain X to Smooth Strain Y



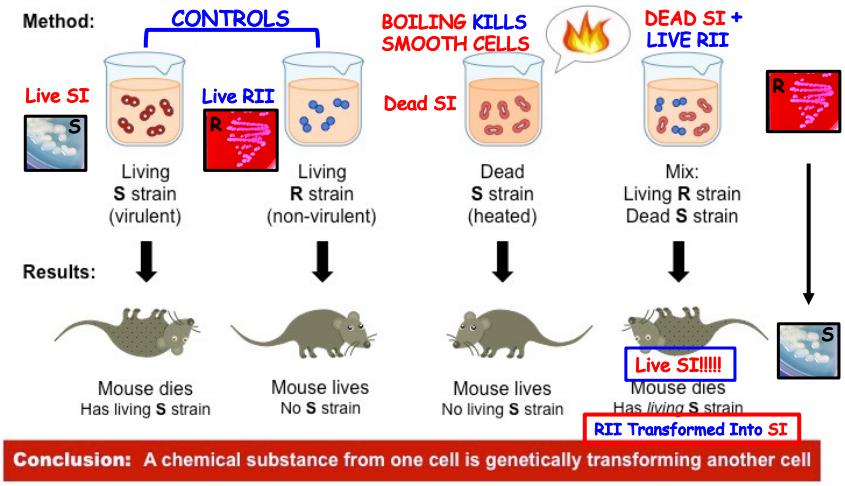




17

The Griffith Experiment (1928)

Hypothesis: Material in dead bacterial cells can transform living bacterial cells

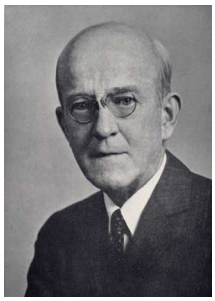


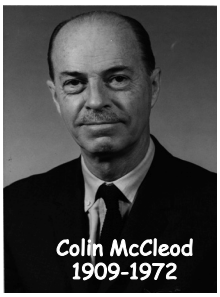
Conclusion: A chemical substance from one cell is genetically transforming another cell

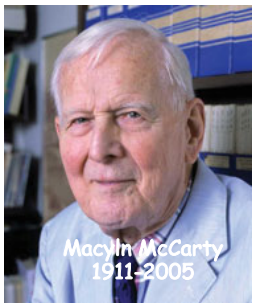
LIVE Rough Cells TRANSFORMED by DEAD Smooth Cells!!!
HOW? What Was the Transforming Principle? Hypothesis?

18

What Was The Transforming Principle?
Experiments of Avery, McCleod, & McCarty
Fast Forward to the 1940s!







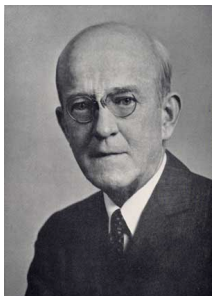
DNA is the Genetic Material!

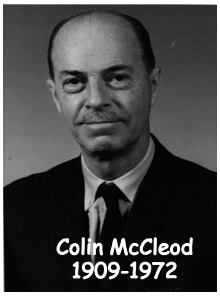
One of the Major Reasons Watson and Crick
Considered DNA As the Genetic Material
In Order to Solve DNA Structure

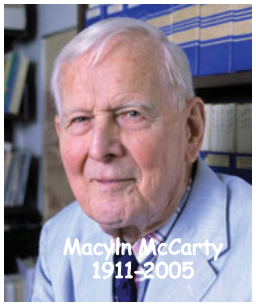
J. Exp. Med.,1944

19

What Was The Transforming Principle?
Experiments of Avery, McCleod, & McCarty
Fast Forward to the 1940s!







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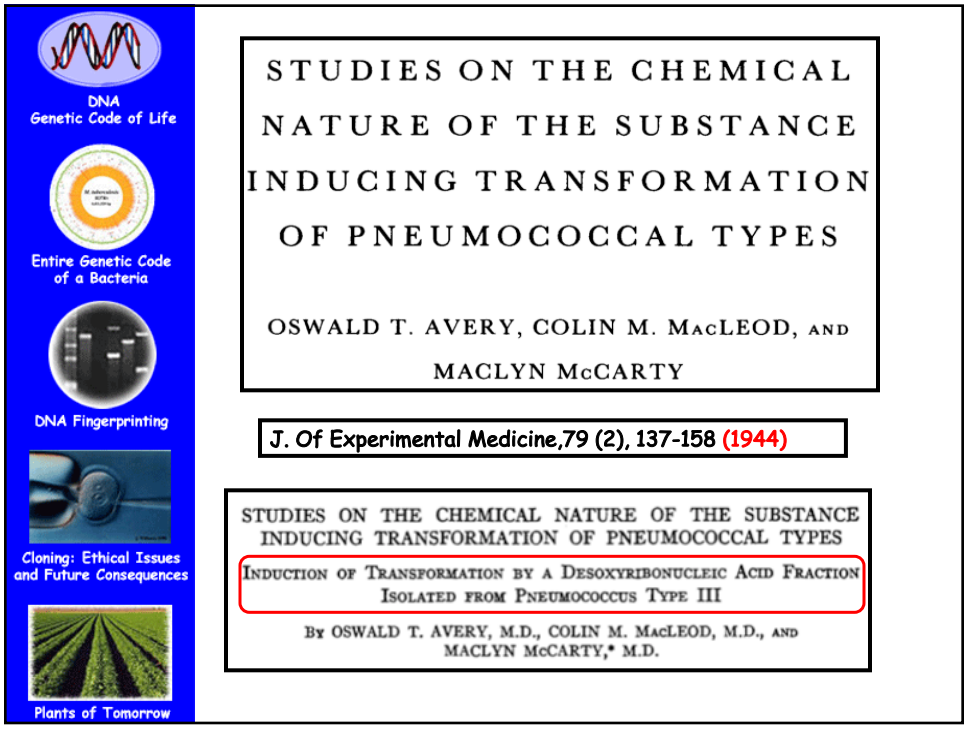


21

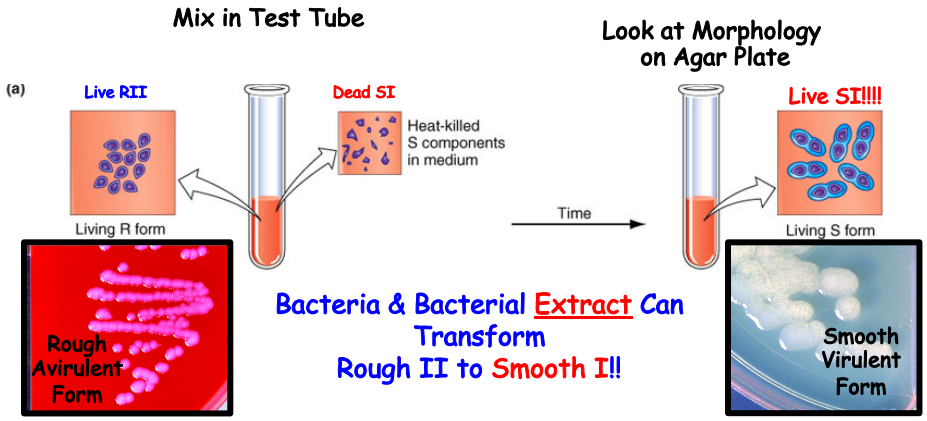
Avery et al.Questions?

1. Does the *Transforming Principle* Come From the Mouse or Bacteria?
2. If From the Bacteria -- What Substance?
3. How Devise Techniques to Determine What the *Transforming Principle* is
   a) Transformation in Test Tube
   b) Isolation of Macromolecules
   c) Isolation of Enzymes (e.g., DNase, RNase)

Design Experiments To Show!!!

22

Does the Transforming Principle Come From the *Mouse* or *Bacteria*?



Bacteria & Bacterial Extract Can Transform Rough II to Smooth I!!

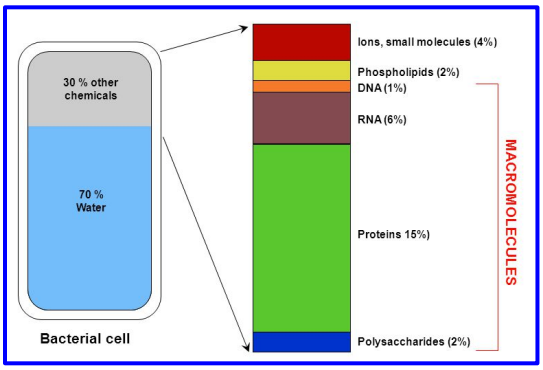
Conclude: (1) Mouse Not Involved & (2) Molecules Inside Bacteria Contain Transforming Principle

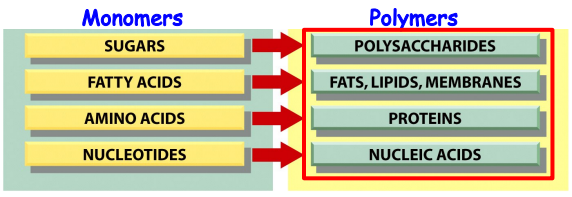
23

What Are the Major Chemical Components of a Bacterial Cell?
What Could Be the Transforming Principle?

1. What is Predicted if DNA is the Genetic Material?

2. How Test Hypothesis?





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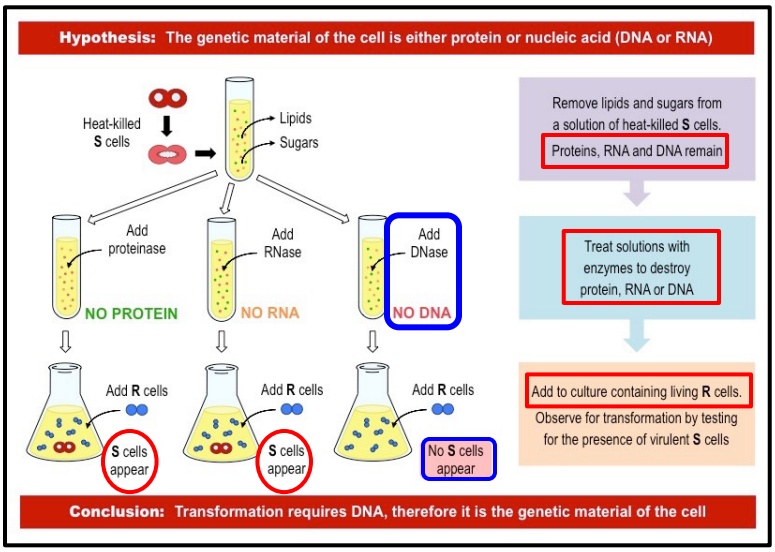
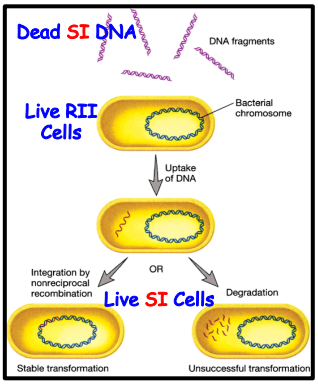
The Critical Experiment by Avery et al.Showing That DNA is the Genetic Material



No DNA – No Transformation!

25

How Did Avery et al. Experiments Validate the Hypothesis That DNA is the Genetic Material?



Predictions	Results
Replication	Yes
Phenotype	Yes
Stable	Yes

Cell Processes

1. SI DNA Taken Up By RII-Cells & Incorporated Into Chromosomes
2. SI Genes Transcribed Into SI mRNAs
3. SI mRNAs Translated Into Smooth I Proteins
4. Smooth I Proteins Helps Construct Sugar Capsule and Protects Bacteria From Antibodies ∴Cells Virulent

1. DNA Satisfies Criteria For Being the Genetic Material
2. Replicates
3. Directs Production of Strain/Capsule Type
4. In All Progenitor Cells

Transformation is a Basic Genetic Engineering Process Today!
Transformation=Ability of Cell Phenotype To Be Changed by DNA!

26

Genetic Engineering/Transformation Involves Incorporating Engineered DNA or Genes Into the Chromosomes of Different Organisms

Genotype → Phenotype

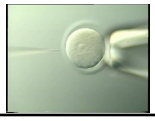
Engineered Gene MUST

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 Trait!

Engineered Gene CAN BE

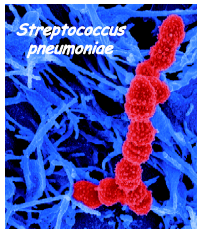
1. From Same Organism
2. From Different Organism
3. From a Combination of Organisms Stitched Together by Genetic Engineering

Gene Engineering Shows that Gene Processes Are Universal!!!


27

All Organisms Can Be Transformed!! Genetic Engineering Has Come a Long Way Since Griffiths Experiments in 1928!!







28

What is A Gene?

Begin 5'

```
TGAAAATCCAAAAAAATAGGA
GTTTGGTGTTTGGGTTTTAGG
TAGGAAATAATTTGGGTCTTT
TTTAGGTTTCGGGTTTGGGTT
ATTTGAGTGTTTGACATTTGA
AATTTCGGTGTTTCATCTTCG
TGGGTGTGCCAGTGGCGTGAG
TGTTCCCCGGTTTCGTCAACT
TACGGTTTAGGGTTTACCAAG
TTAGGGTTTAGGGTTTGAGAT
GGCGGCCATTTCTCATGTTTG
AAACAAAGCCTGAAAATCAAA
TGGGTGTGCCGGTGGCGTGAG
CGTTCCCCGGTTCCGTCAACT
ATCAAGTACCCATGTTTGGGA
TGAACGTCAATGAACACGAAA
AAAAAAATAGGAAATCGACCC
AGAAAAGGGAGGGTGGCCATT
ACTATCACGTAACAACAAAAC
ATTTTTTTGCGTGGGTGTGCC
ATAAATAGATTTTTCCCTTGT
CCTTTTCCATGTTCAAGTACC
TTTCTCATGTTTTGAAGTCAA
CCTGAAAATCCAAAAAAATAG
CAGTGGCGTGAGACATTGGAG
GATACGTCAACTAACACGTAA
CATGTTTGGGATTTTTTTCCG
AGAACCCAAAAAAAATAGTCT
GAAATCGACCCTTTTCCATGT
GGGCAGCCATTTCTCTTGTTT
AAAACAAAGCCTGAATATCTA
GTGAGTGTGCCAGTGGCGTGA
TCGTTCCCCGGTTCCTTCAAC
GTTCAAGTACCCATGTTTGGG
TTGGACGTCAAAGAAACCAAA
CAAAAAAATAGGAAATCGACC
AGAAAATGGAGGGCGGCCAAT
CTGACACGTAAAAACAAAGCT
TTTTTTCGCGTGGGTGTGCCA
AAAATAGTCCCGTTCCCCGTT
TTTTCCATGTTCAATTACCCA
TCTCATATTTGGACGTCAAAG
```

End 3'

Sequence or Order of Nucleotides Coding DNA Strand (Coding Strand)

The β-Globin Gene

Blood Protein Carries Oxygen to All Genes From Lungs ⇨ Energy

A Gene is a Unique Sequence of Nucleotides Specifying a Function

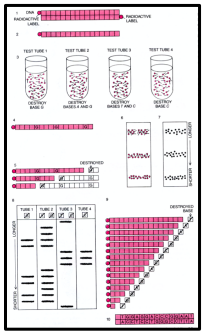
DNA Sequence = Biology!
What If Sequence Changed?

SEQUENCE → FUNCTION

Relative to Coding or Sense Strand of Gene

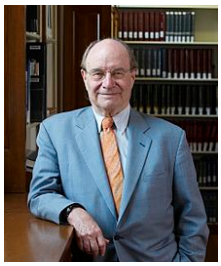
29

Genes and Genomes Can Be Sequenced!

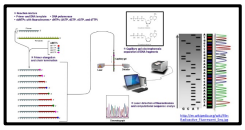


A new method for sequencing DNA
(DNA chemistry/dimethyl sulfate cleavage/hydrazine/piperidine)
ALLAN M. MAXAM AND WALTER GILBERT
PNAS February, 1977

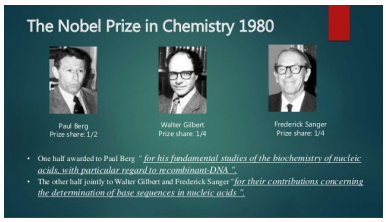
Water Gilbert



Fred Sanger



DNA sequencing with chain-terminating inhibitors
(DNA polymerase/nucleotide sequences/bacteriophage ϕX174)
F. SANGER, S. NICKLEN, AND A. R. COULSON
PNAS December, 1977



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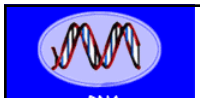


DNA
Genetic Code of Life

Entire Genetic Code of a Bacteria

DNA Fingerprinting

Cloning: Ethical Issues and Future Consequences

Plants of Tomorrow

Genes & Genomes Differ Because the Sequence of DNA Differs!!

DNA Sequence Beginning → End
5' 3'

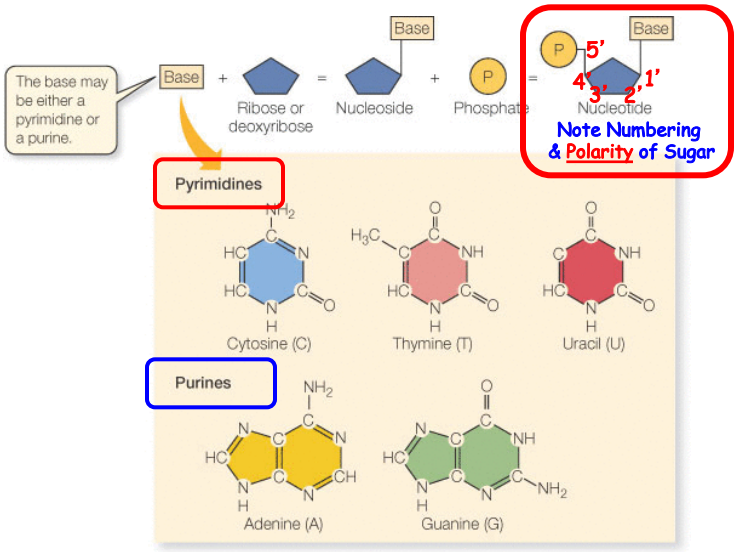
→ Biological Uniqueness

If You Know the DNA Sequence, You Can Engineer Anything! Even Make New Genes & Genome!

Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome

31

There Are Four Different Nucleotides in DNA



Polarity of Sugar Leads to Polarity of DNA (and RNA) – 5' to 3"

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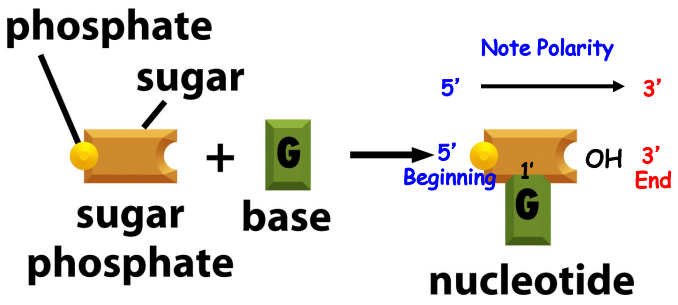
Nucleotides Have Polarity
Based on What is Bonded to the Five-Carbon Sugar
Phosphate on 5' Carbon and OH on 3' Carbon



The Sugar is the HUB

DNA Sequence Defined By Nucleotide Order

DNA Sequence = Functional Uniqueness = Biology

Figure 1-2a *Molecular Biology of the Cell*, Fifth Edition (© Garland Science 2008)

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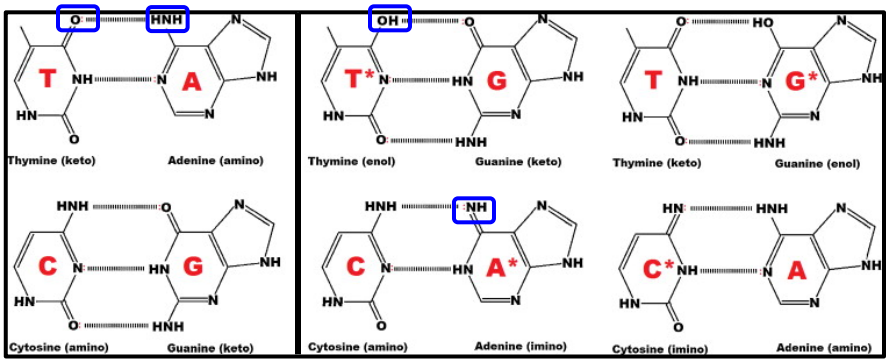
Tautomers Change Base Pairing Rules!!!

Normal Forms – Keto & Amino

"Mutant" Forms – Enol & Imino



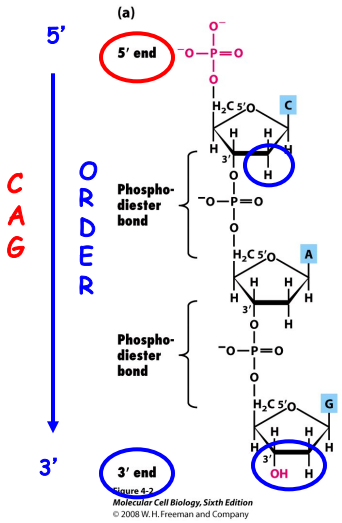
And Lead To Mistakes in DNA Replication & Mutations ➡ Genetic Diversity

Chemistry Leads to Biology!!

34

Nucleotides Are Joined By 5' to 3' Phosphodiester Bonds

Polarity Defined By Sugars & Order Specified By Bases



1. Nucleotides That Join 5' to 3'
2. This is the Basis For All of Biology
3. Order is Maintained During DNA Replication
4. Basis of All Genetic Engineering

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Clues to the Double Helix-Chargaff's Rules

Purines = Pyrimidines

TABLE 6.1 Chargaff's Data on Nucleotide Base Composition in the DNA of Various Organisms

	Percentage of Base in DNA				Ratios	
Organism	*A*	*T*	*G*	*C*	*A:T*	*G:C*
Staphylococcus afermentams	12.8	12.9	36.9	37.5	0.99	0.99
Escherichia coli	26.0	23.9	24.9	25.2	1.09	0.99
Yeast	31.3	32.9	18.7	17.1	0.95	1.09
*Caenorhabditis elegans**	31.2	29.1	19.3	20.5	1.07	0.96
*Arabadopsis thaliana**	29.1	29.7	20.5	20.7	0.98	0.99
Drosophila melanogaster	27.3	27.6	22.5	22.5	0.99	1.00
Honeybee	34.4	33.0	16.2	16.4	1.04	0.99
Mus musculus (mouse)	29.2	29.4	21.7	19.7	0.99	1.10
Human (liver)	30.7	31.2	19.3	18.8	0.98	1.03

*Data for *C. elegans* and *A. thaliana* are based on those for close relative organisms.
Note that even though the level of any one nucleotide is different in different organisms, the amount of A always approximately equals the amount of T, and the level of G is always similar to that of C. Moreover, as you can calculate for yourself, the total amount of purines (A plus G) nearly always equals the total amount of pyrimidines (C plus T).

What Would You Predict For a Single-Stranded DNA?

THE COMPOSITION OF THE DESOXYPENTOSE NUCLEIC ACIDS OF THYMUS AND SPLEEN*

ERWIN CHARGAFF, ERNST VISCHER,† RUTH DONIGER, CHARLOTTE GREEN, AND FERNANDA MISANI

J. Biological Chemistry, July, 1948

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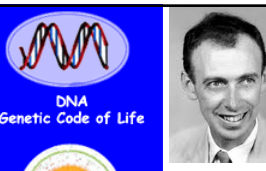
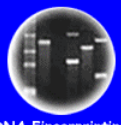
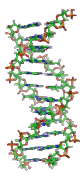
Clues to the Double Helix-Chargaff's Rules
Purines = Pyrimidines

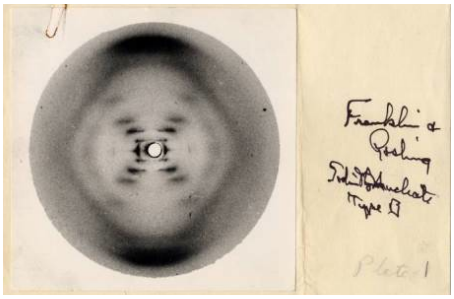
37

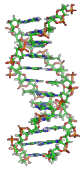




Reflections on *The Double Helix*







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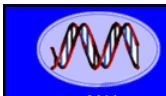
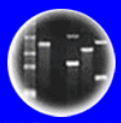


DNA
Genetic Code of Life

Entire Genetic Code of a Bacteria



DNA Fingerprinting

Cloning: Ethical Issues and Future Consequences

Plants of Tomorrow

MOLECULAR STRUCTURE OF NUCLEIC ACIDS

A Structure for Deoxyribose Nucleic Acid

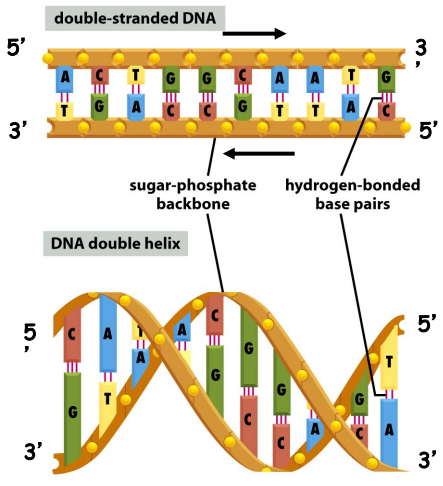
WE wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable biological interest.

Nature, April 25, 1953

We are much indebted to Dr. Jerry Donohue for constant advice and criticism, especially on interatomic distances. We have also been stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M. H. F. Wilkins, Dr. R. E. Franklin and their co-workers at

39

DNA is a Double Helix of Two Complementary Chains of DNA Wound Around Each Other



1. Complementary Strands
2. A=T and G=C (Four Bases)
3. Sequence of Strands Differ
4. Bases to Interior
5. Phosphate-Sugar Backbone on Exterior
6. DNA Strands in Opposite Direction (Only Way Helix Fits)
7. Sequence of One Chain Automatically Specifies Sequence of Complementary Chain (Basis of Replication!)
8. No Constraint on Sequence
   (4^n=n # base combinations = Diversity)

DNA has dimensions (Know # bp Know Length: 20Å diameter, 3.4Å/bp, 10bp/turn)

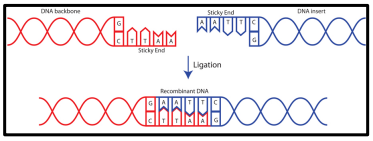
9. Sequence = Biology

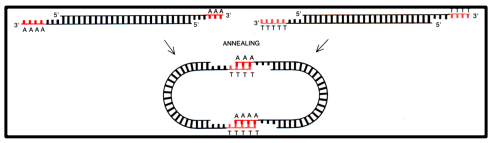
Watson and Crick, Nature, 1953

40

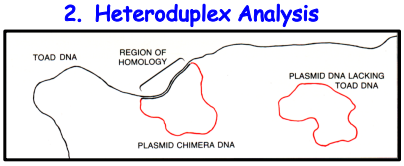
Complementary Base Pairs Are Essential For Genetic Engineering Engineering, Analysis of Recombinant Plasmids, and Polymerase Chain Reaction (PCR)

1. Annealing Two Two Molecules Together ("Cut & Splice")

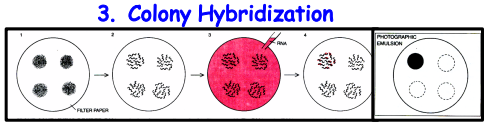




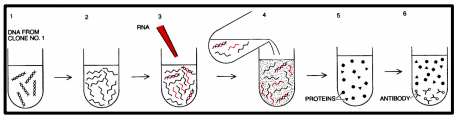
2. Heteroduplex Analysis



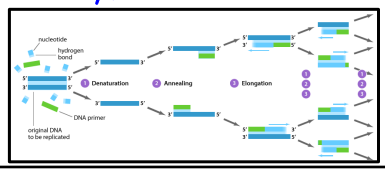
3. Colony Hybridization



4. Hybrid-Arrested Translation



5. Polymerase Chain Reaction



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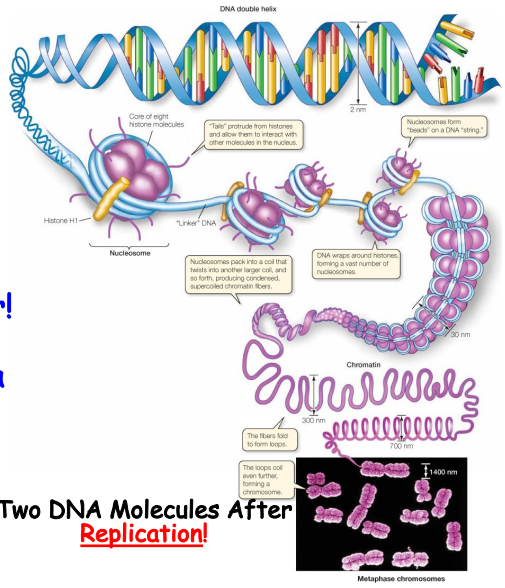
A Chromosome Contains One (or Two!!) Continuous DNA Molecule(s)

DNA in Human & Eukaryotic Chromosomes is Linear!

DNA in Most Bacteria is Circular!



Two DNA Molecules After Replication!

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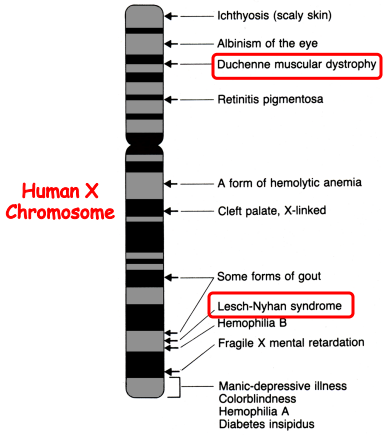
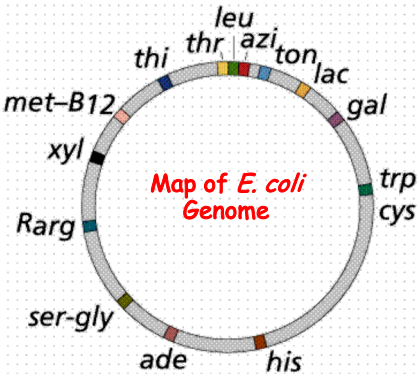
Genes Reside at Specific Locations That Can Be Mapped



Linear DNA
How Know?



Circular DNA
How Know?

- Note Marker Bands - What are these? How are they useful?
- How Determine Gene Positions? Chromosome Number?

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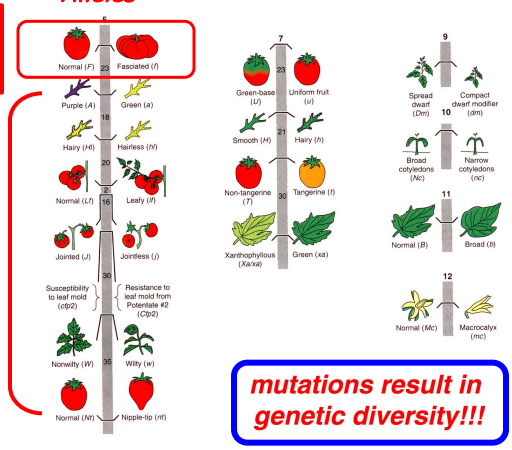
Alleles Reside at the Same Position on a Chromosome

Allele Phenotypes Specify Markers For Each Gene Location!

Alleles

Different Genes



mutations result in genetic diversity!!!

Gene Engineering Can Generate New Forms of Alleles of a Gene and, therefore, Results in More Genetic Diversity

Alleles Are Different Forms of the Same Gene
That Arise By Mutation & Can be Made in a Laboratory
By Modern Genetic Engineering!

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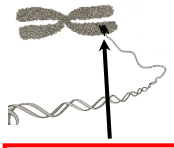
A Chromosome Contains Many Genes Operating Independently
What is the Evidence?

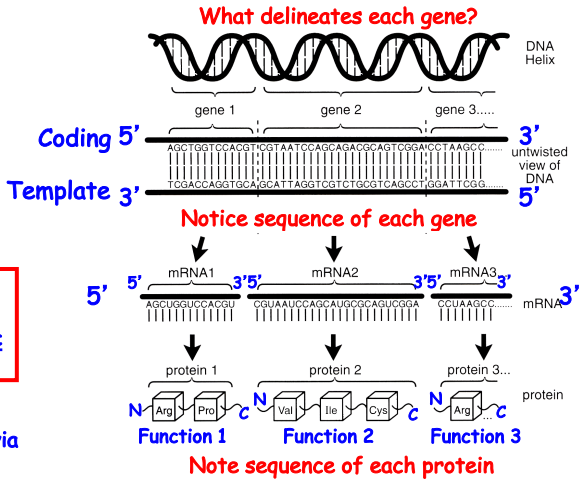


Position of Genes 1, 2, & 3 in chromosome

Discrete Units!

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

Central Dogma
∴ Genes -> Functions in Cells via Proteins
Cells duplicate & stay the same -> DNA replication



VERY IMPORTANT CONCEPT!
COLINEARITY BETWEEN GENE SEQUENCE AND PROTEIN SEQUENCE

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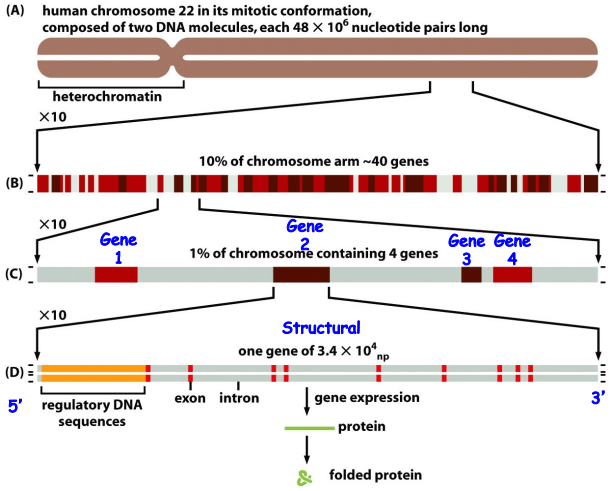
Organization of Genes on Human Chromosome 22



250 genes

Genes Are Defined/Precise Regions of DNA

One Large Gene!

Genes Act As Individual Units?
How Know? GloFish Experiment! Genetic Engineering Antibiotic^R

Figure 4-15 *Molecular Biology of the Cell* (© Garland Science 2008)

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A Conceptualized Gene

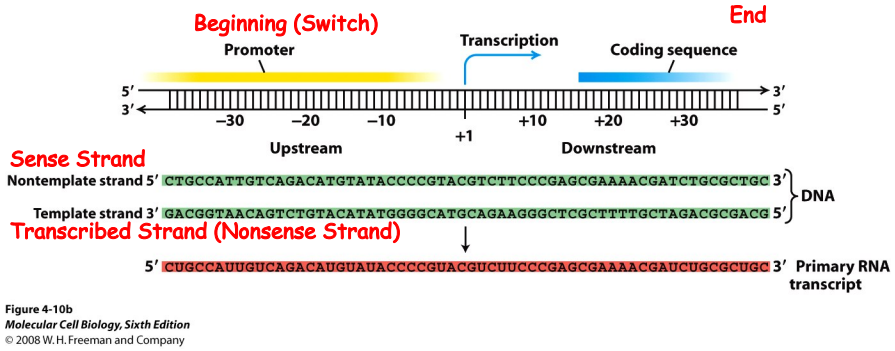

Figure 4-10b
Molecular Cell Biology, Sixth Edition
© 2008 W. H. Freeman and Company

Major Concept in *"Making Proteins in Recombinant Bacteria"* Article by Gilbert

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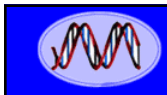
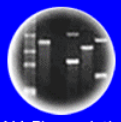

DNA
Genetic Code of Life


Entire Genetic Code of a Bacteria


DNA Fingerprinting


Cloning: Ethical Issues and Future Consequences


Plants of Tomorrow

A "Simple" Gene Reviewed

1. Sense Strand = Genetic Code
2. Sense Strand = 5' → 3' Direction (all DNA sequences specified 5' → 3')
3. Anti Sense Strand = Complement of Sense Strand & is Transcribed Strand
4. mRNA = Same Sequence As Sense Strand & Complementary to AntiSense Strand
5. mRNA = 5' → 3'
6. Switch Turns Gene On - Not Transcribed But Upstream of Coding Region

Genes Function As Independent Units! How Know? Design Experiment to Show!

"Everything" Follows the Double Helix & Its Rules - Anti-parallel Chains & Complementary Base Pairing!

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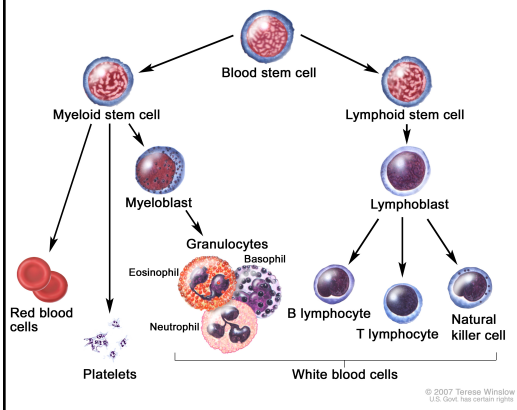
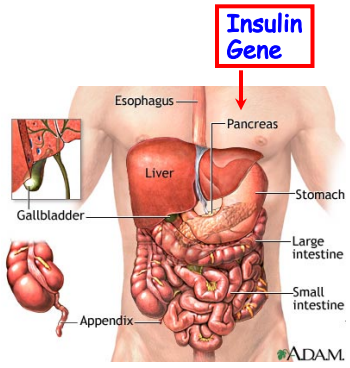
Switches Control Where & When A Gene Is Active → Unique Functions → Unique Cells





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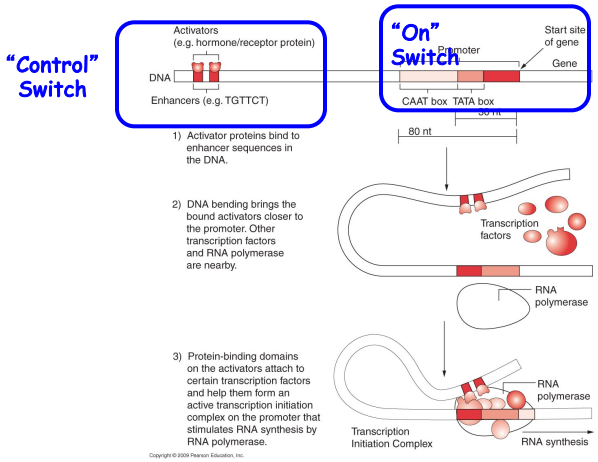
Control Switches Are Unique DNA Sequences & Can Be Cloned

AND used to Re-Engineer Organisms!!
Switches Act Independently of Gene!!



1. Each Switch Has a Unique DNA Sequence
2. Genome Projects Reveal Genes & Logic Controlled by the Switches
3. Sequence = Biology
4. No Hocus Pocus
5. Yo! It's in the DNA!!

Legos!!!

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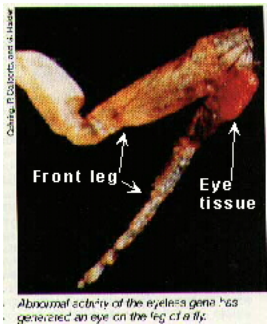
The Eye Gene Can Be Expressed in Different Parts of the Fly by Engineering the Eye Switch

Eye Gene

Replace the Head Switch With the Leg Switch by Genetic Engineering

Eye Gene
+
Leg Switch



Abnormal activity of the eyeless gene has generated an eye on the leg of a fly.

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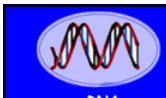
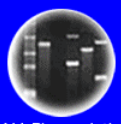


DNA
Genetic Code of Life

Entire Genetic Code of a Bacteria



DNA Fingerprinting

Cloning: Ethical Issues and Future Consequences

Plants of Tomorrow

Eye Regulatory Network

Control Genes Like The Eye Gene Control The Activity of Other Genes!

5' 3'

Eye Switch | Eye Gene

Works in Head!

Eye Protein

Eye Structure Genes

Gene 1 → Protein 1
Gene 2 → Protein 2
Gene 3 → Protein 3
Gene 4 → Protein 4

Eye Protein Binds to Switches to Turn Genes On!

Eye on Head!

Leg Switch | Eye Gene

Normally Eye Gene is OFF in Leg. Switch only Works in Leg.

Eye Protein

Eye Structure Genes

Gene 1 → Protein 1
Gene 2 → Protein 2
Gene 3 → Protein 3
Gene 4 → Protein 4

Eye on Leg!

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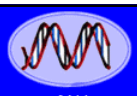

DNA
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100 Years Into The Future

1. If the Entire Human Genome is Sequenced?
2. If the Function/Protein 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 Law Were Only Rediscovered 120 Years Ago & Look What We Can Do & Now!

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