



Lecture 19:

Regulation of gene expression

I. Generalities

Course 281

Lessons for life

It doesn't matter how many "resources" you have if you don't know how to use them.

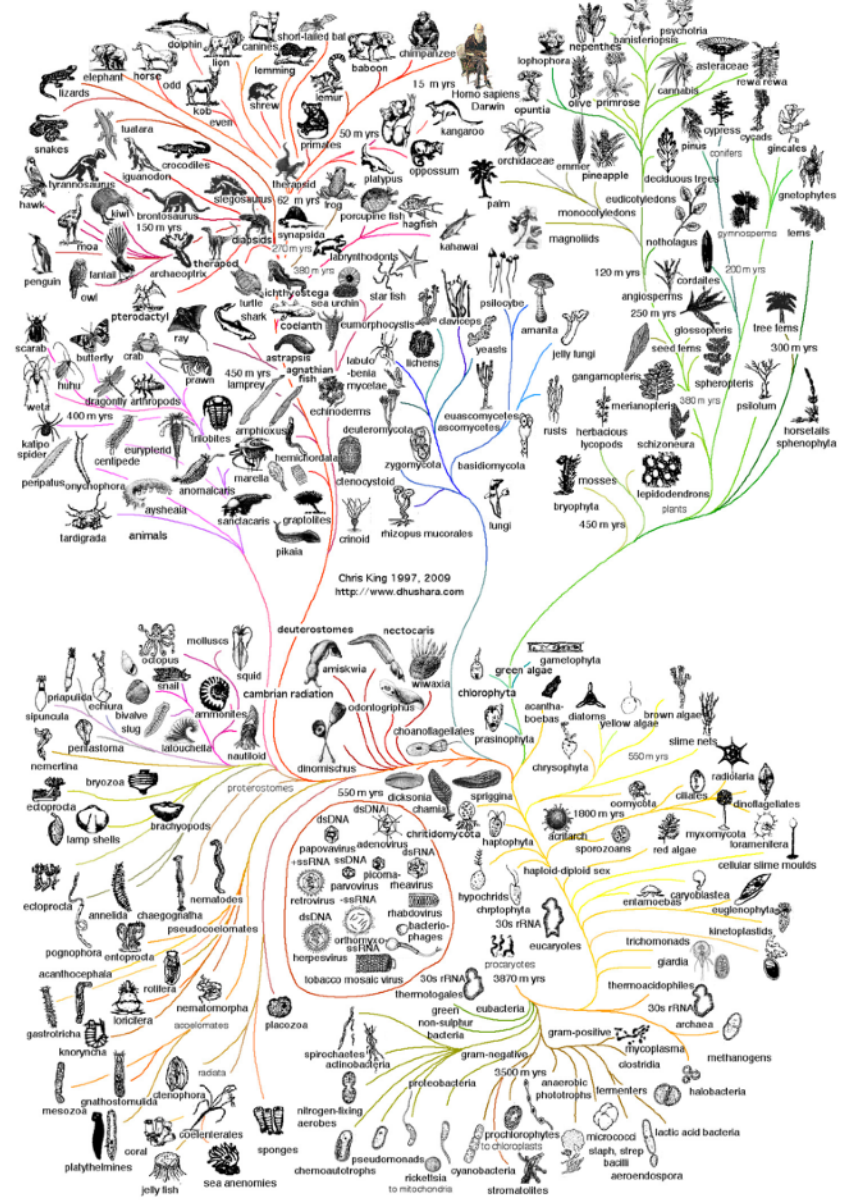


AIMS

- Understand the the importance of the regulation of gene expression.
- Understand when gene expression can be controlled both in prokaryotes and eukaryotes.
- Understand the overall structure of the genes' molecular switches.
- Understand what DNA motifs are.
- Understand the different classes of regulatory proteins.

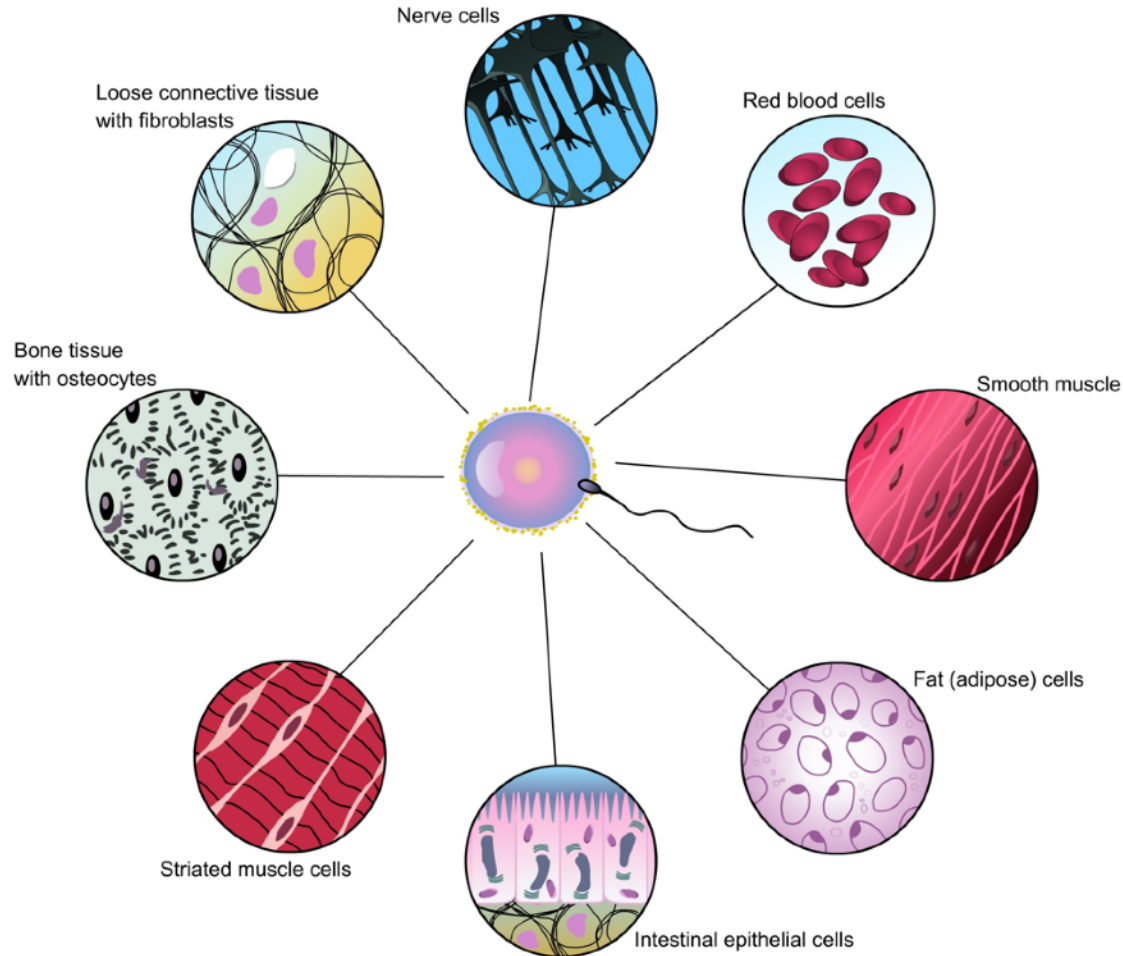
Overview

- DNA encodes all RNAs and proteins needed for the cell/organism.
- Genes make almost every character of a cell/organism.



Overview

One cell (zygote) divides and differentiates to make so many cell types



Overview

The differentiation depends on changes in
gene expression

NOT

on a change in the genes or the nucleotides of
the genome.

Overview

How do we know that the genes are the same in all cells and some have not been lost by some cellular mechanisms?

- Experiments that show that the genome of differentiated cells is the same and can be re-programmed to make any other cell type.
- Among such experiments are the cloning experiments.

Experiments: empty cell to synthetic bacteria

Chemical synthesis of a bacterial genome and placing it in an empty cell

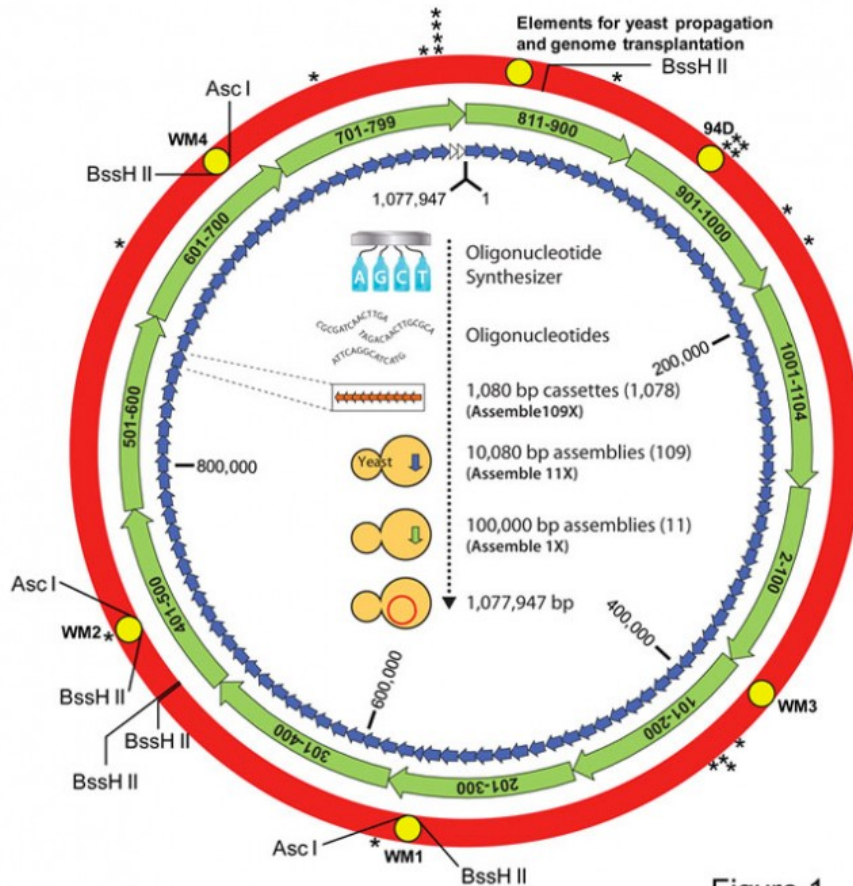


Figure 1

HOW CRAIG VENTER'S TEAM CREATED THE SYNTHETIC CELL AND HOW IT WILL BE PUT TO USE

- 1** Scientists make short strands of DNA from the four chemical building blocks of life (adenine, guanine, cytosine and thymine), based on the DNA sequence of the microbe *Mycoplasma mycoides*.

'GENE MACHINE'

Short DNA strands created

A G C T

CCGCATCAACTTGA
TAGACAACCTGGCA
ATTGAGGCATCATG
- 2** Short DNA strands transferred into yeast cells to "repair" them into bigger molecules of DNA which are then transferred into *E. coli* and back into yeast to build up the DNA into a chromosome one billion units long.

Short DNA strands

E. coli

Artificial chromosome

Yeast cells

Yeast cells
- 3** The artificial chromosome is inserted into an empty cell of *Mycoplasma capricolum* with none of its own DNA left.

Artificial chromosome

EMPTY CELL

Natural chromosome removed

One billion replications of all genes and proteins from original synthetic chromosome

BIOFUELS
Converting carbon dioxide into hydrocarbons that could be turned into fuel is the holy grail of synthetic biology. Venter is working with Exxon-Mobil to design microbes that can do this, in the hope of finding a clean source of energy.

CLEAN WATER
Millions of people do not have access to safe drinking water, a situation that will only get worse with a growing population. Synthetic lifeforms are seen as one possible solution to a problem exacerbated by water contamination.

POLLUTION CLEAN-UP
Microbes that can "eat" waste oil or remove poisonous chemicals and heavy metal pollutants from landfill sites would revolutionise our ability to deal with toxic spills and waste dumps. Synthetic life could be one solution.

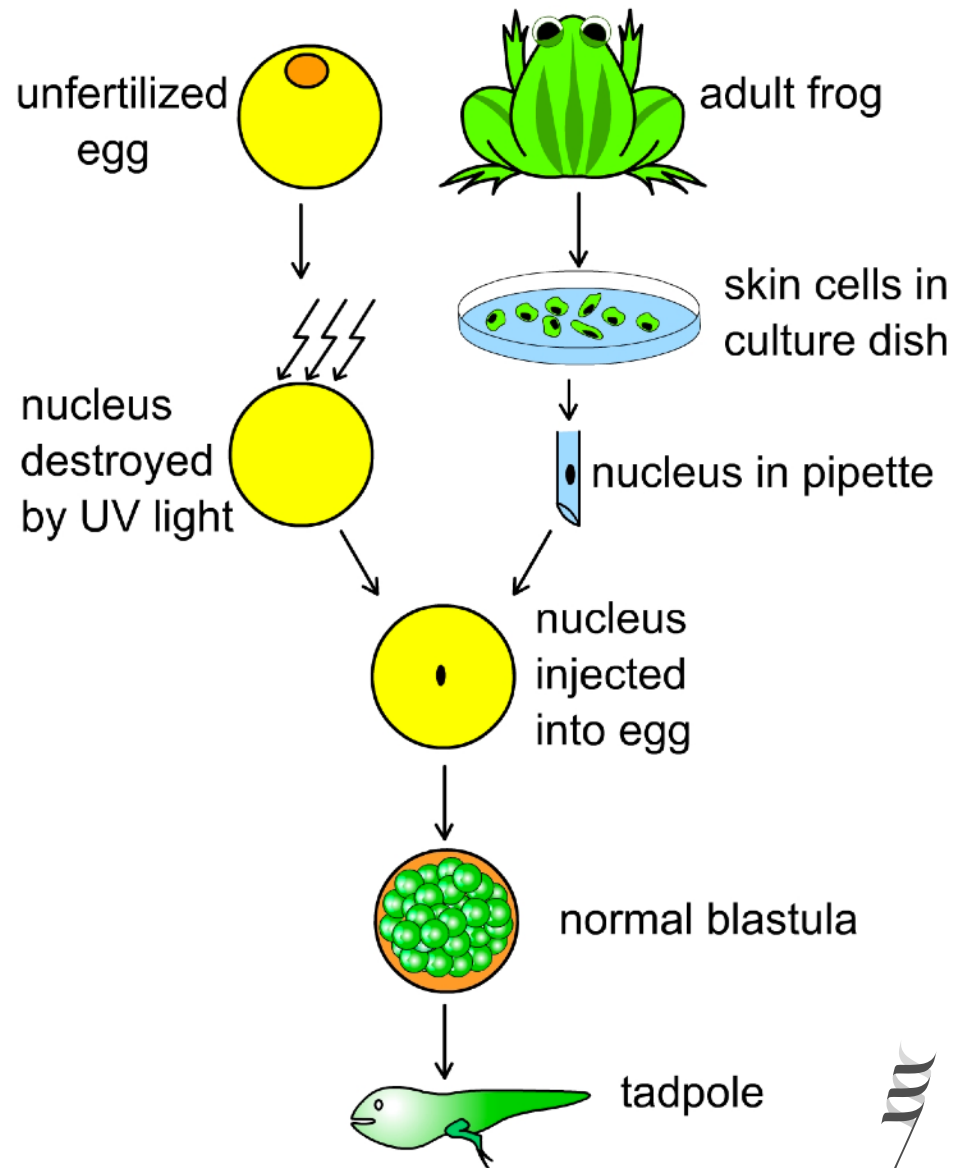
NEW VACCINES/DRUGS
Venter hopes to be able to design artificial life forms that can quickly make vaccines on huge production scales to reduce the time it takes between a new disease emerging and an effective treatment. Drug companies are interested.

NEW SOURCES OF FOOD
With the global population set to rise from 6.8 billion to 9 billion, scientists warn we will have to come up with revolutionary ways of producing food. Would synthetic life offer a potential solution? Venter believes it does.



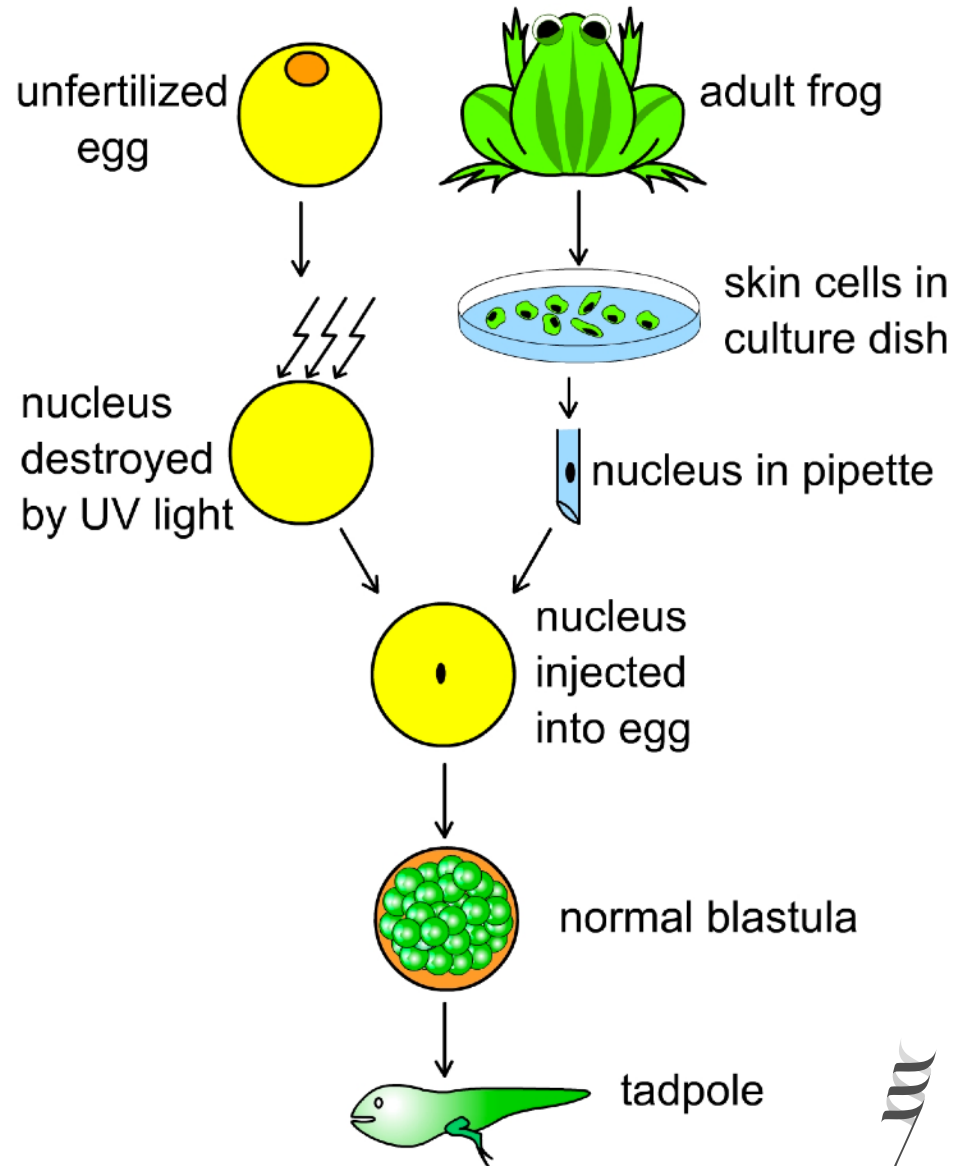
Experiments: green skin to froggy

- Take skin cells and remove the nucleus.
- **Skin cells are differentiated. Correct?**
- Take unfertilized egg and remove the chromosomes. **You now have empty egg.**



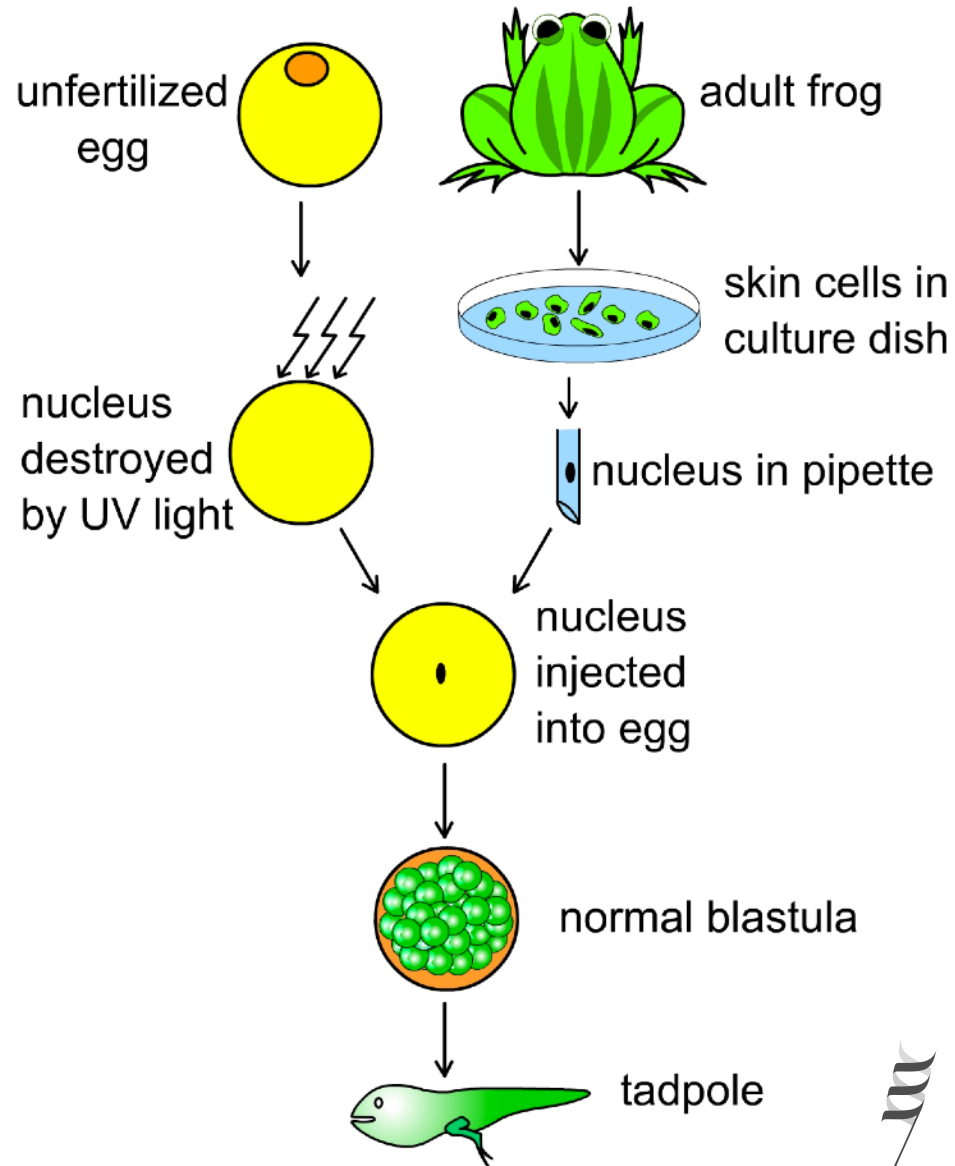
Experiments: green skin to froggy

- Take the nucleus of the skin cell (chromosomes) and put them in the empty egg.
- Let it grow.



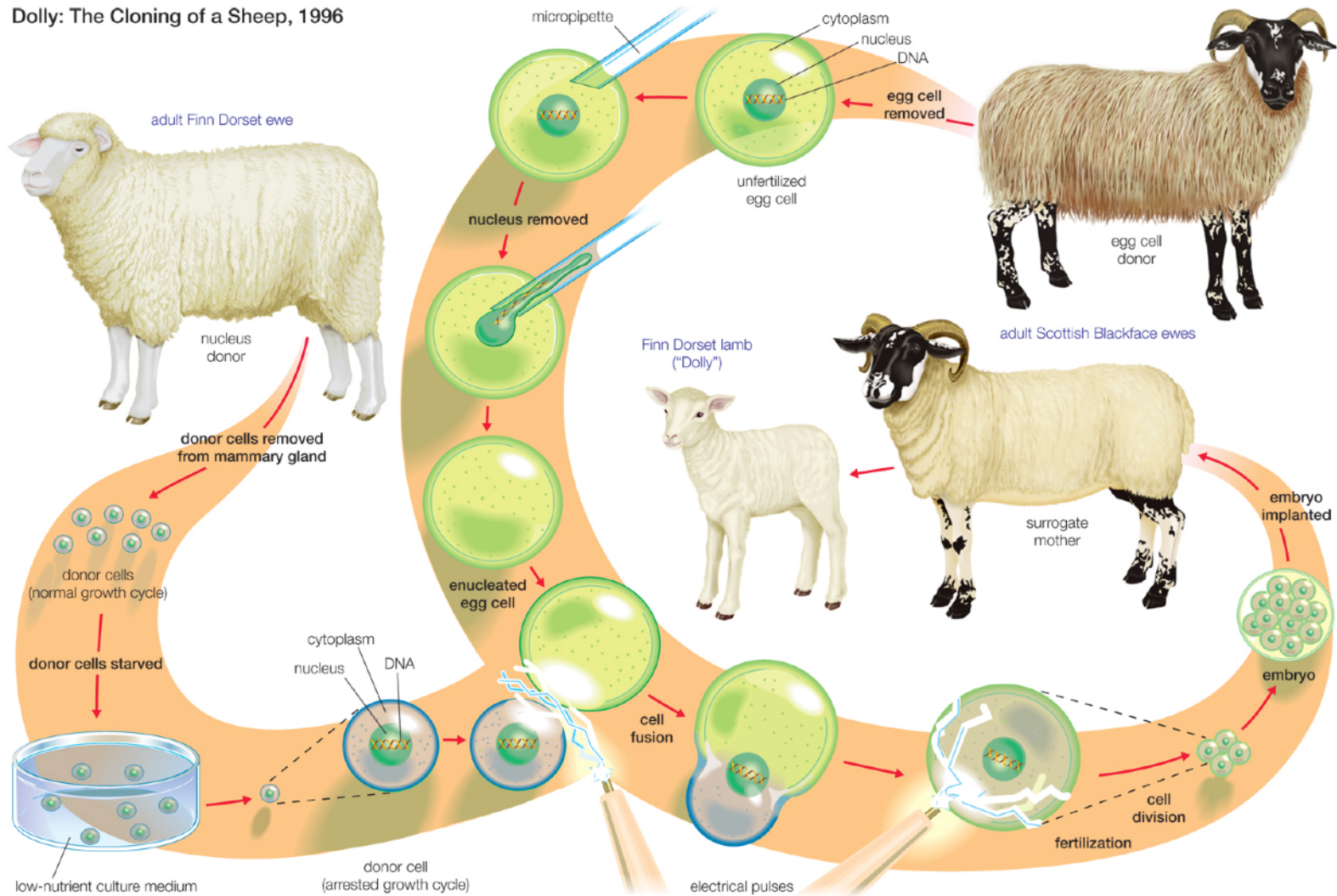
Experiments: green skin to froggy

- The cell will grow into a full organism.
- **Conclusion:**
 - **The genes in the skin cell can regenerate all other types of cells.**
 - **Genes are the same.**



Experiments: Dolly the sheep

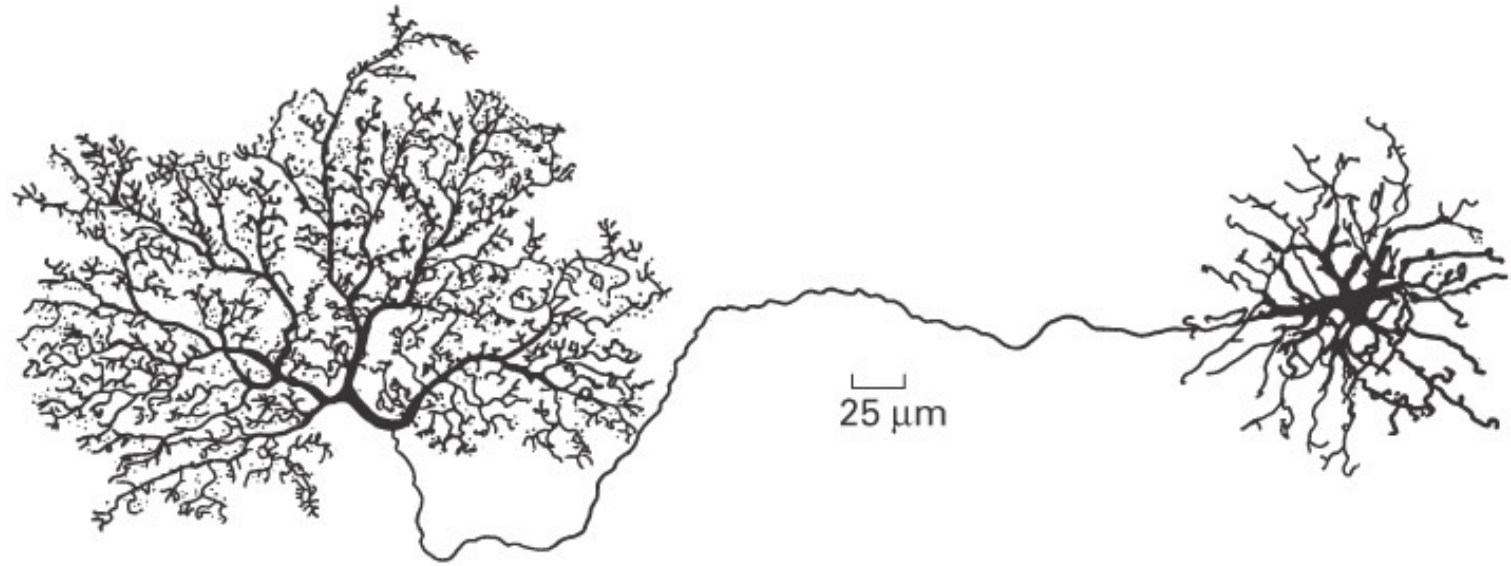
Dolly: The Cloning of a Sheep, 1996



Overview

- Consider the differences between a nerve cell and a lymphocyte.
- Both cells have the same genome.
- **But they differ in:**
 - Size
 - Shape
 - Function

Overview



neuron



lymphocyte

Overview

What are the conditions to make one specific product?

When to express one gene or another?

What mechanisms control gene expression?

General statements

- Many processes in the cell are the same across different types of cells.
- Thus cells have the same genes expressed and proteins/RNA made.
- These genes maintain the basic functions of the cell.

General statements

Examples:

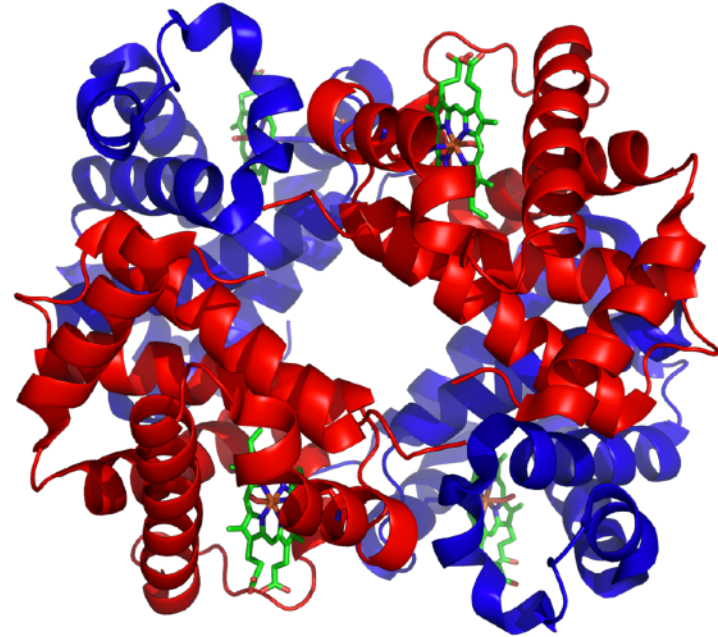
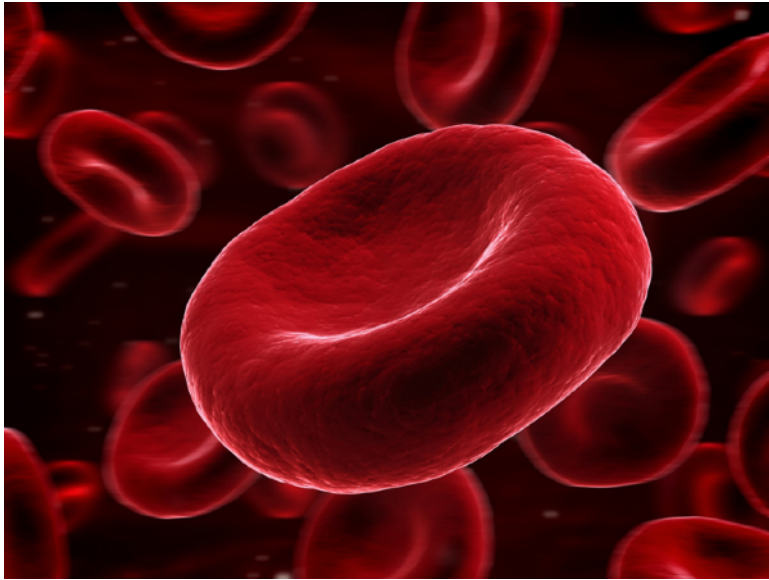
RNA polymerase - DNA repair enzymes
Ribosomal proteins – rRNA – tRNA – Etc.

- These genes are called **housekeeping genes or constitutive genes**.
- These genes are switched **ON** almost all the time.

General statements

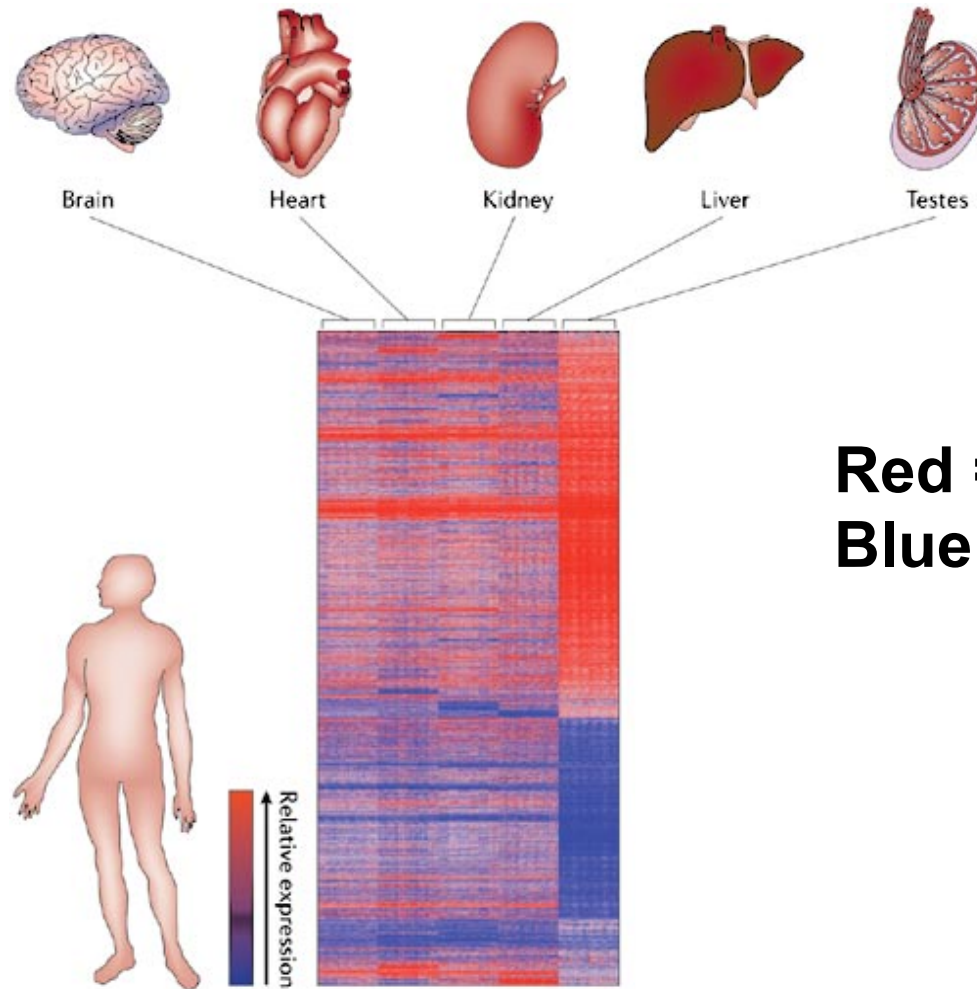
- Some proteins are found only in a specific specialized cells and not in any other cells.
- **Example:** Hemoglobin is found only in red blood cells.
- Such genes are referred to as **regulated genes**.
- These genes gets switched **ON** and **OFF** depending on the need and location (cell type).

General statements



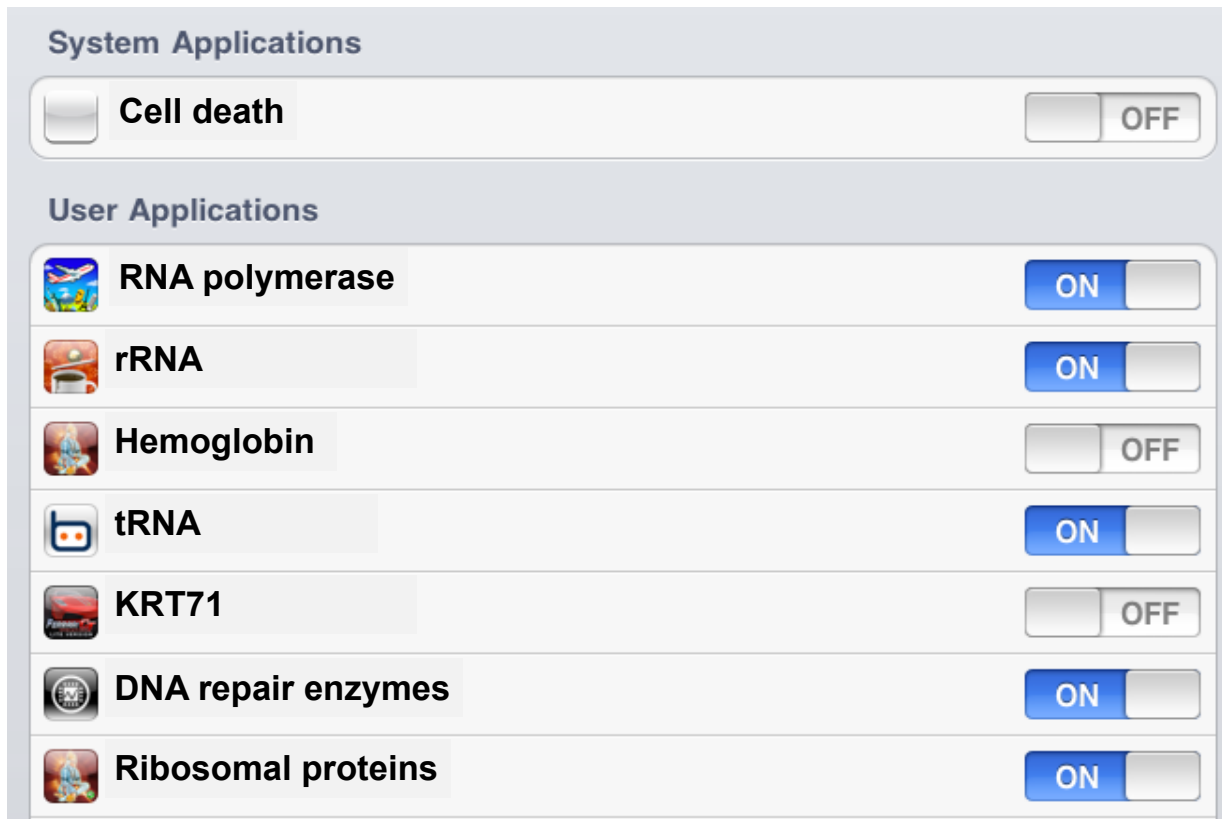
General statements

Levels of expression of mRNA (# of genes switched **ON**) is different depending on location and time



Gene expression

Regulation of gene expression is simply turning genes ON and OFF as needed



The screenshot displays a control panel for gene expression. It is divided into two main sections: 'System Applications' and 'User Applications'. Each application has a corresponding icon and a toggle switch to control its status.

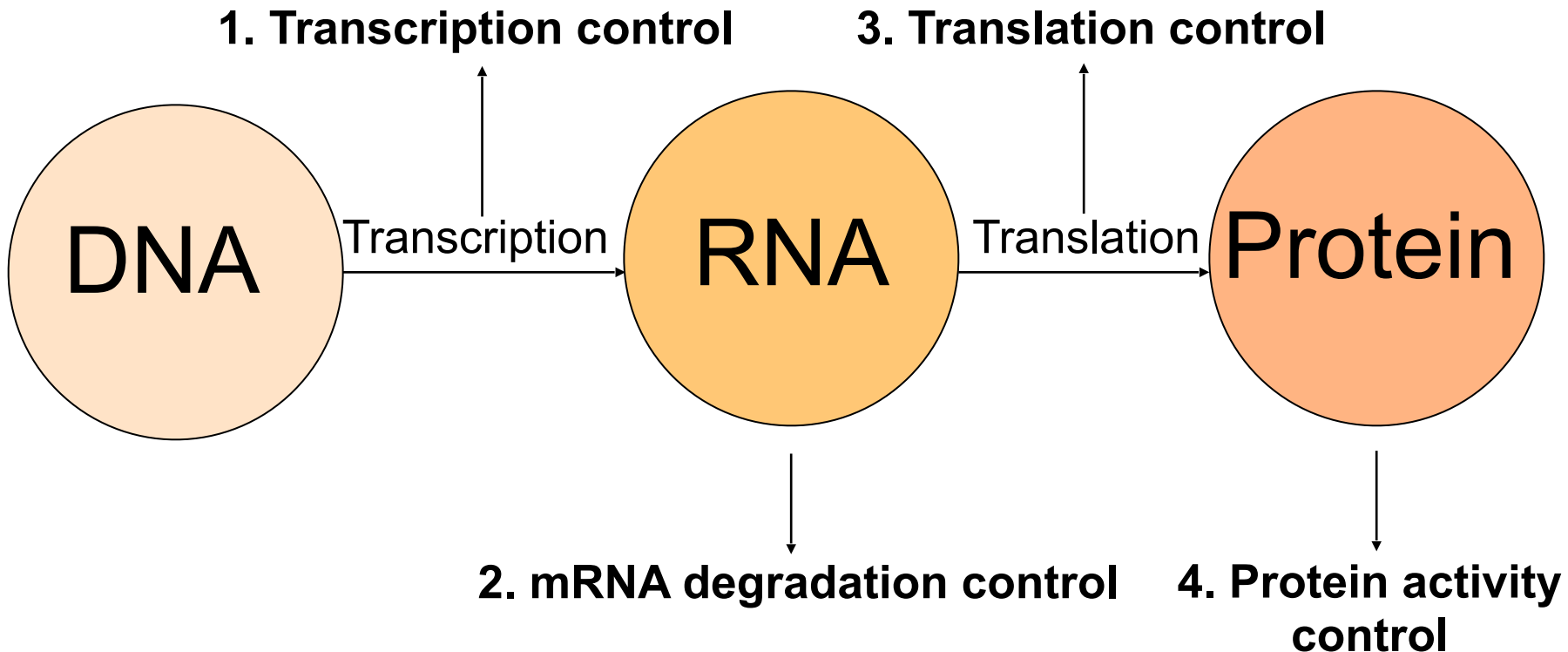
Application	Status
Cell death	OFF
RNA polymerase	ON
rRNA	ON
Hemoglobin	OFF
tRNA	ON
KRT71	OFF
DNA repair enzymes	ON
Ribosomal proteins	ON

Gene expression

When in the pathway of gene expression regulation takes place?

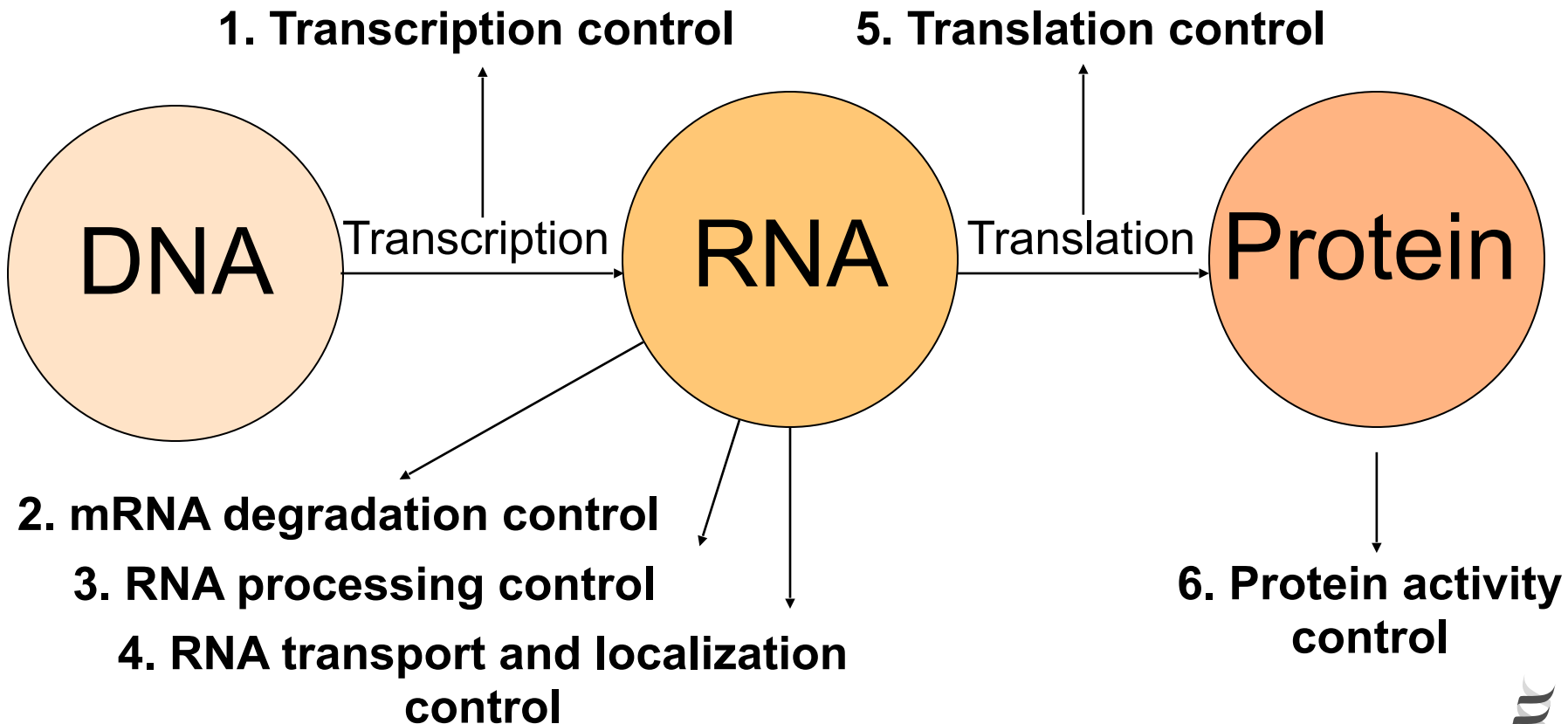
Regulation of Gene expression

Prokaryotes: regulation of gene expression can take place at multiple stages during the transcription/translation process.



Regulation of Gene expression

Eukaryotic: regulation of gene expression can take place at multiple stages during the transcription/translation process.



Regulation of Gene expression

- **Transcriptional control:** controlling when and how often a gene is transcribed.
- **RNA processing control:** controlling how a transcript is being spliced or processed.
- **mRNA degradation control:** selectively choosing mRNA in the cytoplasm for destabilization and degradation.
- **RNA transport and localization:** controlling which mature mRNA leaves the nucleus to the cytoplasm and where.

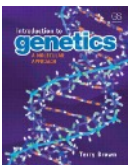
Regulation of Gene expression



- **Translational control:** controlling which mRNA in the cytoplasm gets translated by ribosomes.
- **Protein activity control:** selectively choosing a protein for activation, inactivation, or degrading.

9.1 THE IMPORTANCE OF GENE REGULATION

- Gene regulation enables bacteria to respond to changes in their environment
- Gene regulation in eukaryotes must be responsive to more sophisticated demands
- The underlying principles of gene regulation are the same in all organisms



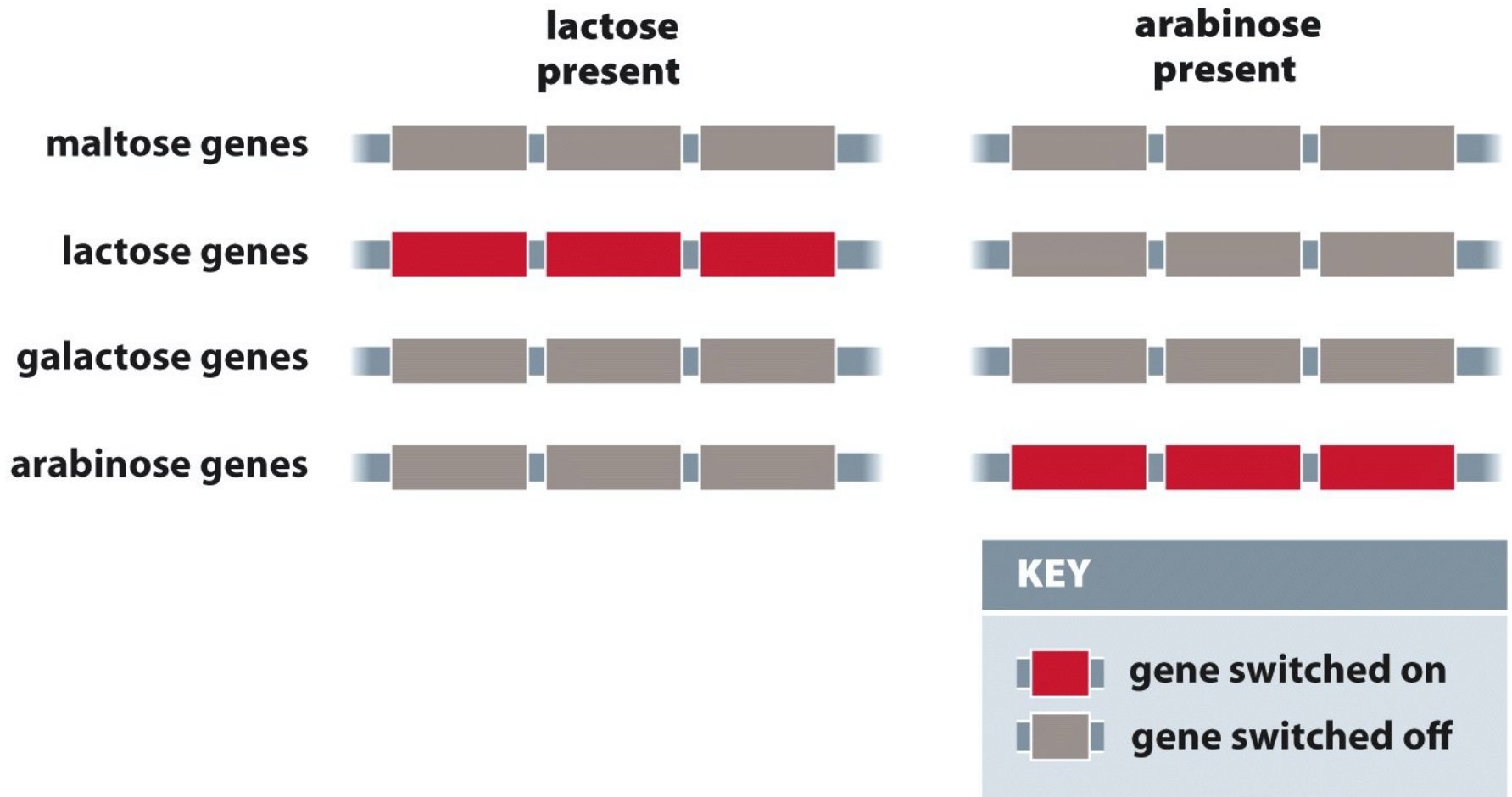
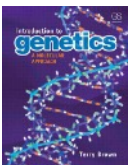
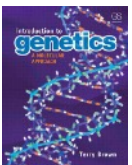


Figure 9.1 Introduction to Genetics (© Garland Science 2012)

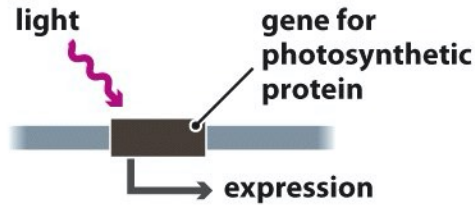


9.1 THE IMPORTANCE OF GENE REGULATION

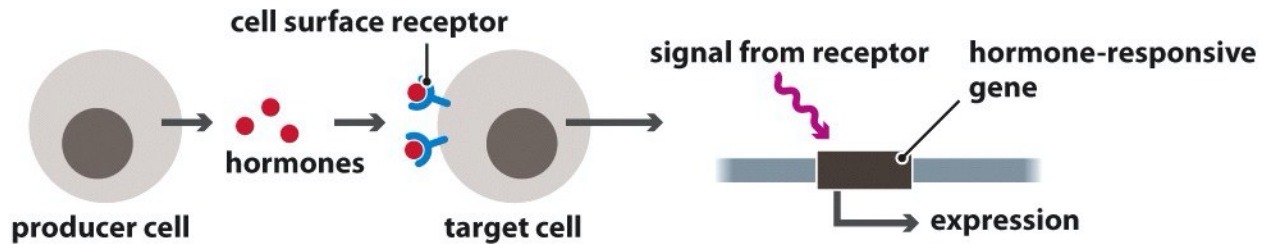
- Gene regulation enables bacteria to respond to changes in their environment
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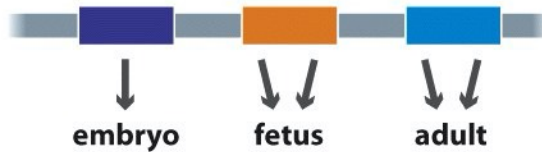
(A) plant genes respond to light



(B) hormones and other regulatory molecules control gene expression



(C) β -globin genes are developmentally regulated



(D) specialized cells express different genes

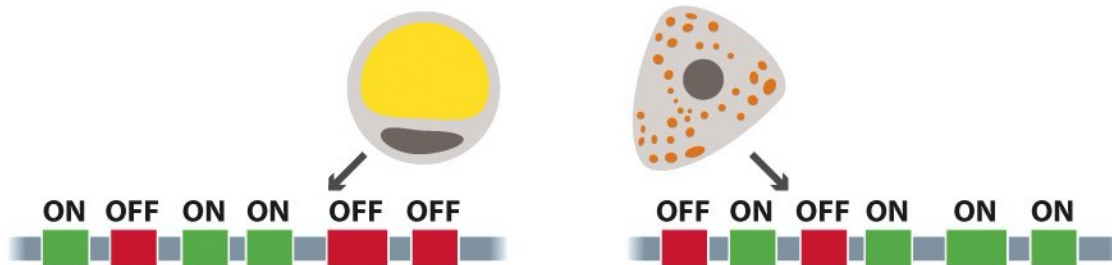
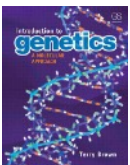


Figure 9.2 Introduction to Genetics (© Garland Science 2012)



plant genes respond to light

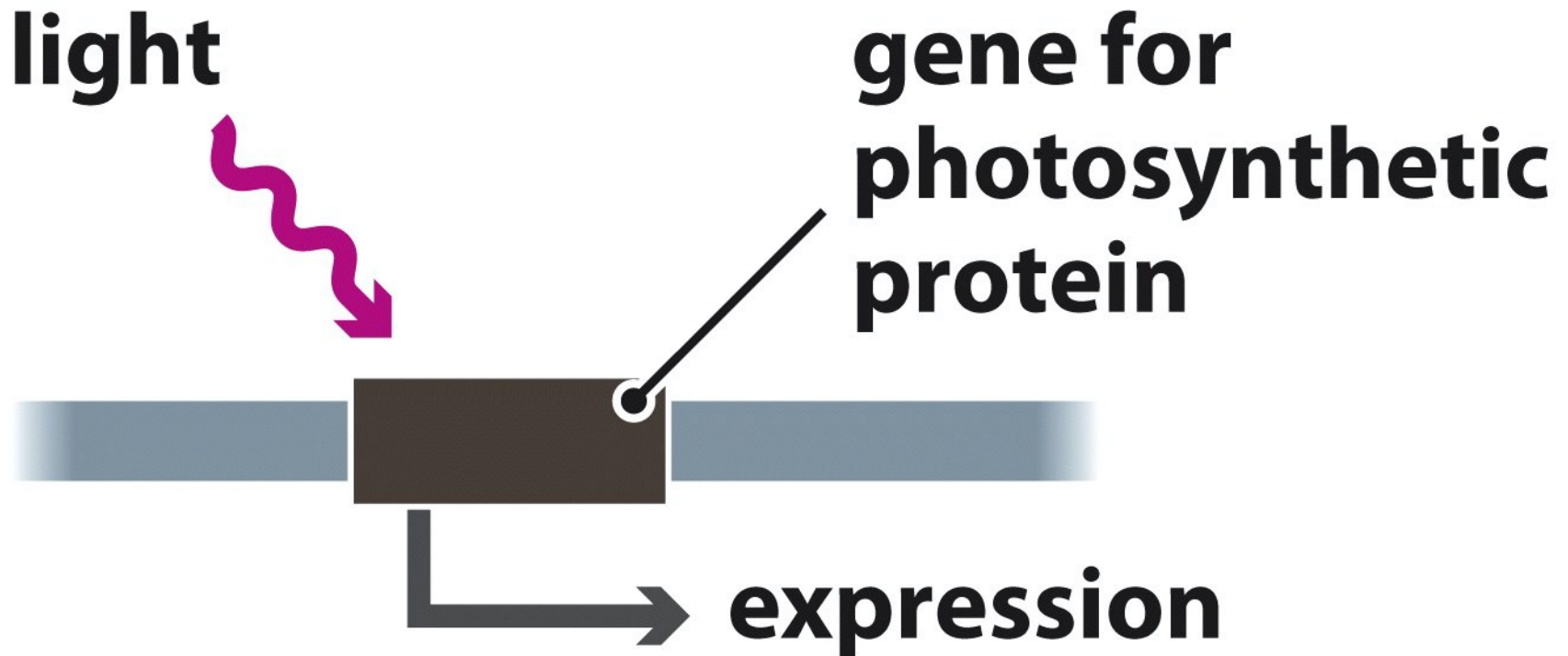


Figure 9.2a Introduction to Genetics (© Garland Science 2012)

hormones and other regulatory molecules control gene expression

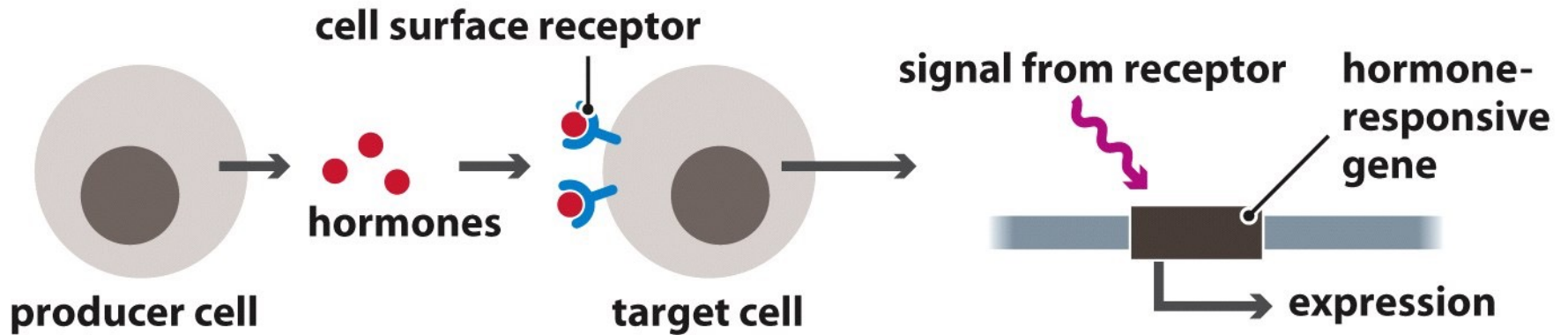


Figure 9.2b Introduction to Genetics (© Garland Science 2012)

β -globin genes are developmentally regulated

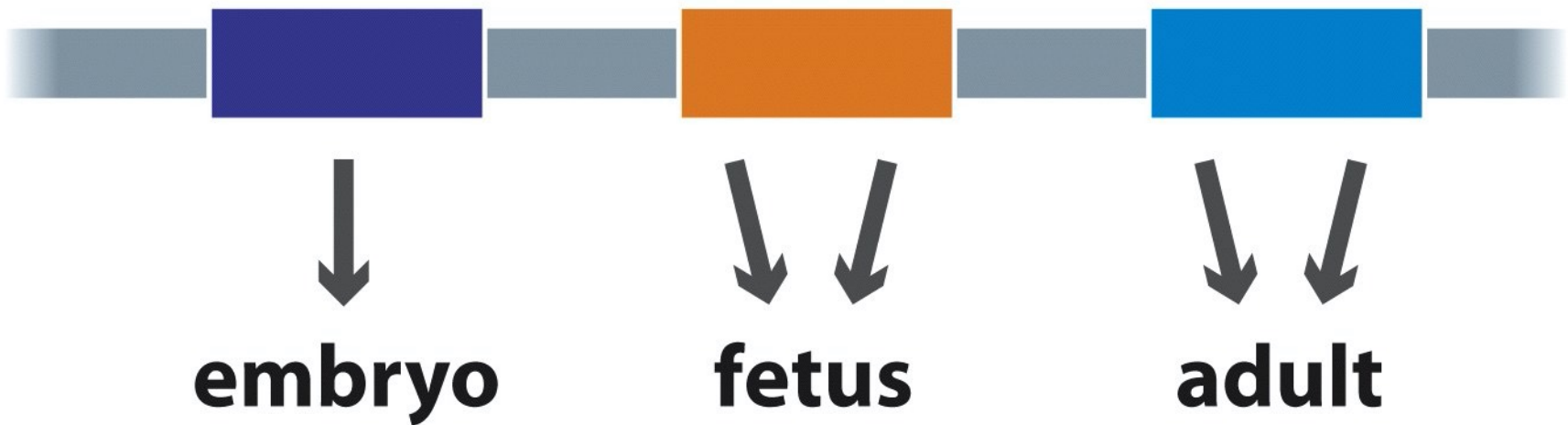


Figure 9.2c Introduction to Genetics (© Garland Science 2012)

specialized cells express different genes

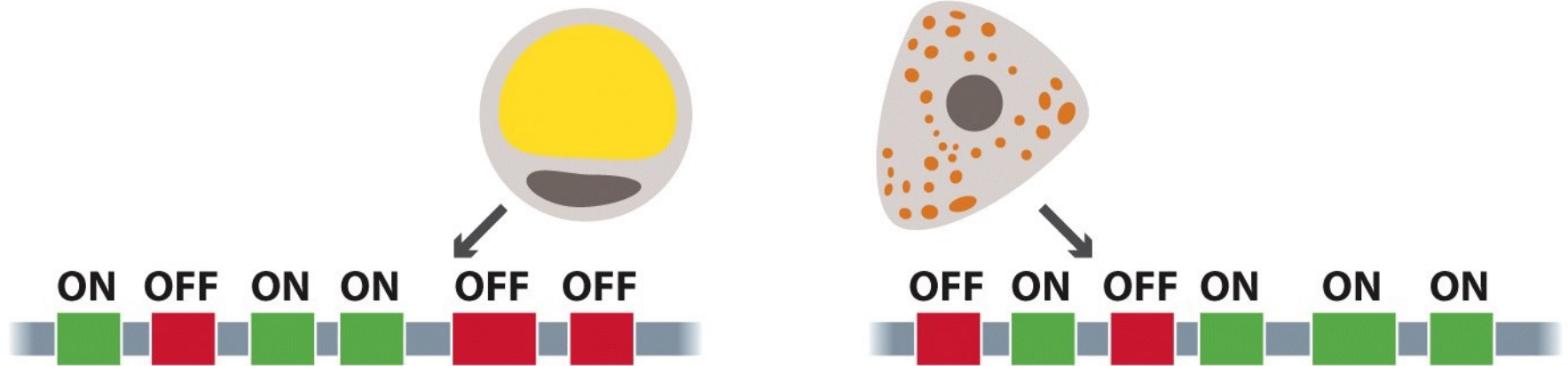
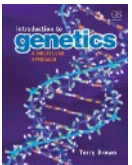


Figure 9.2d Introduction to Genetics (© Garland Science 2012)

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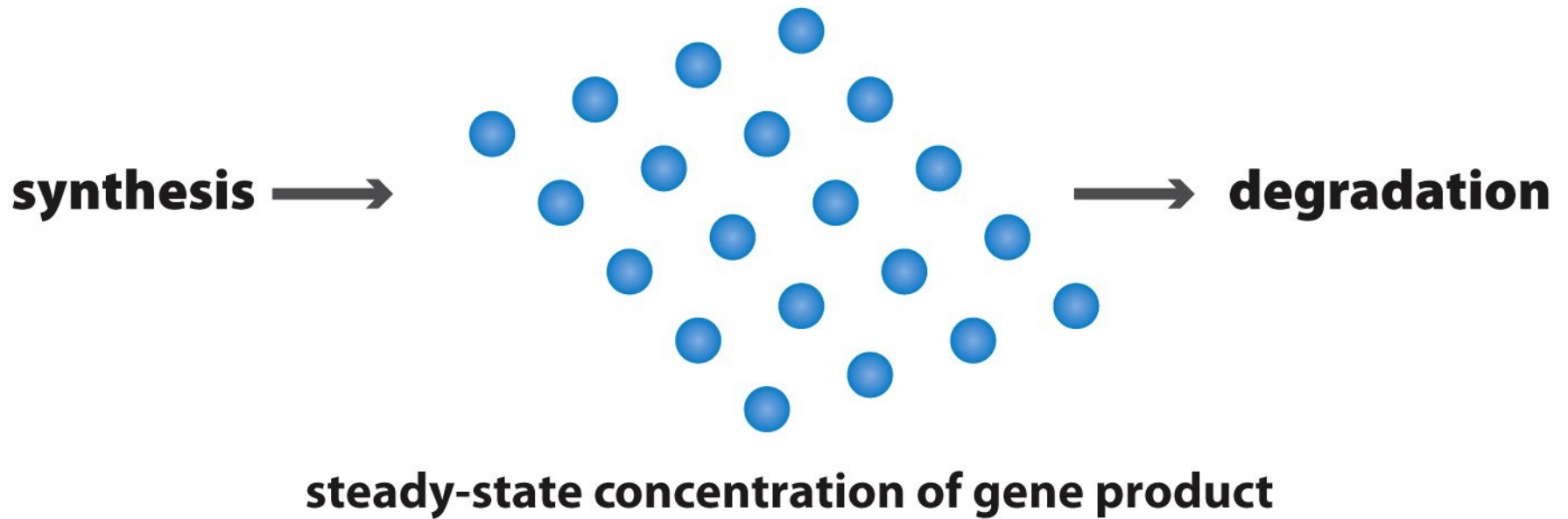
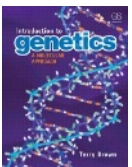


Figure 9.3 Introduction to Genetics (© Garland Science 2012)



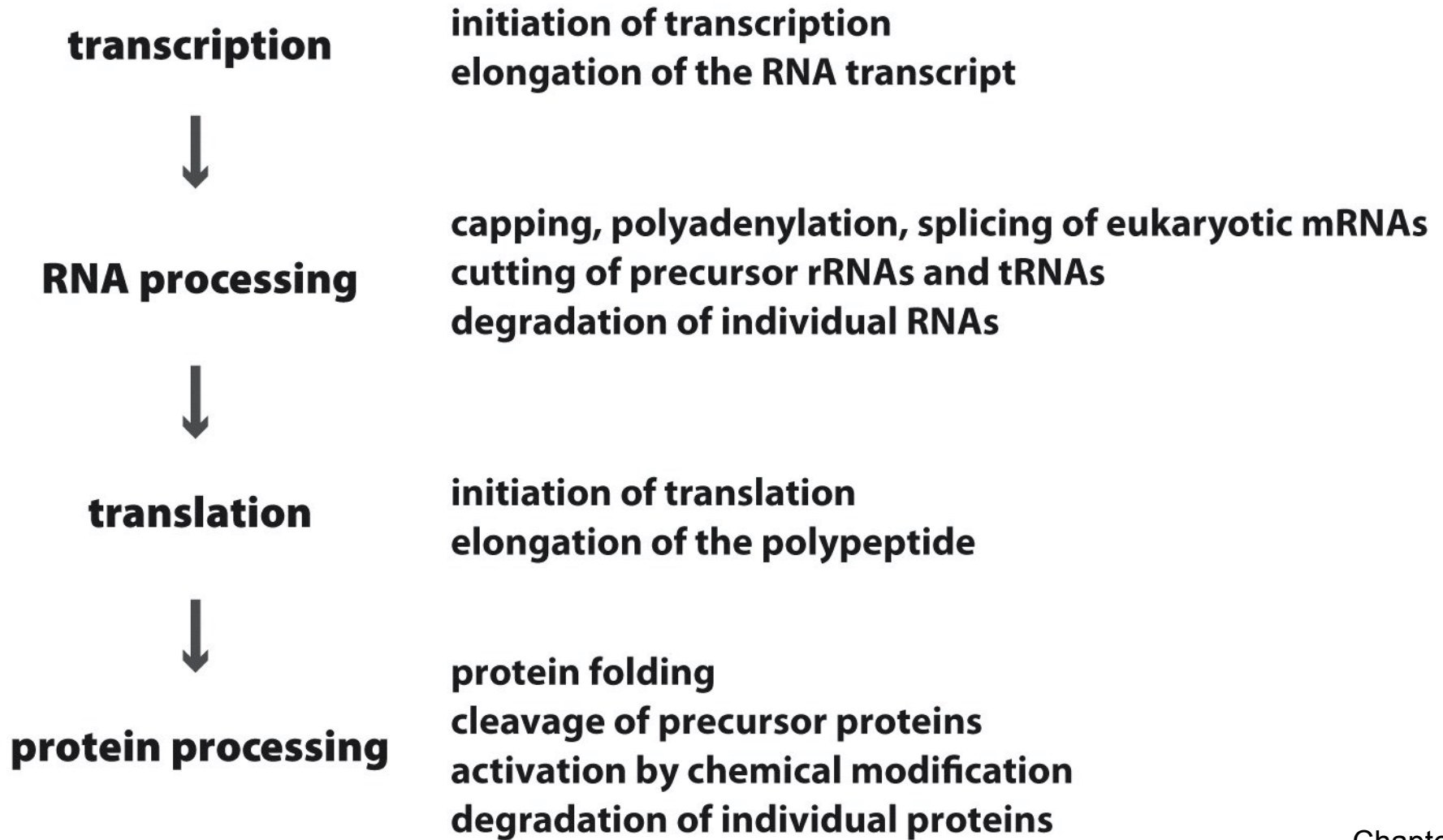
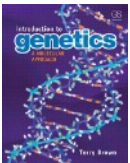


Figure 9.4 Introduction to Genetics (© Garland Science 2012)



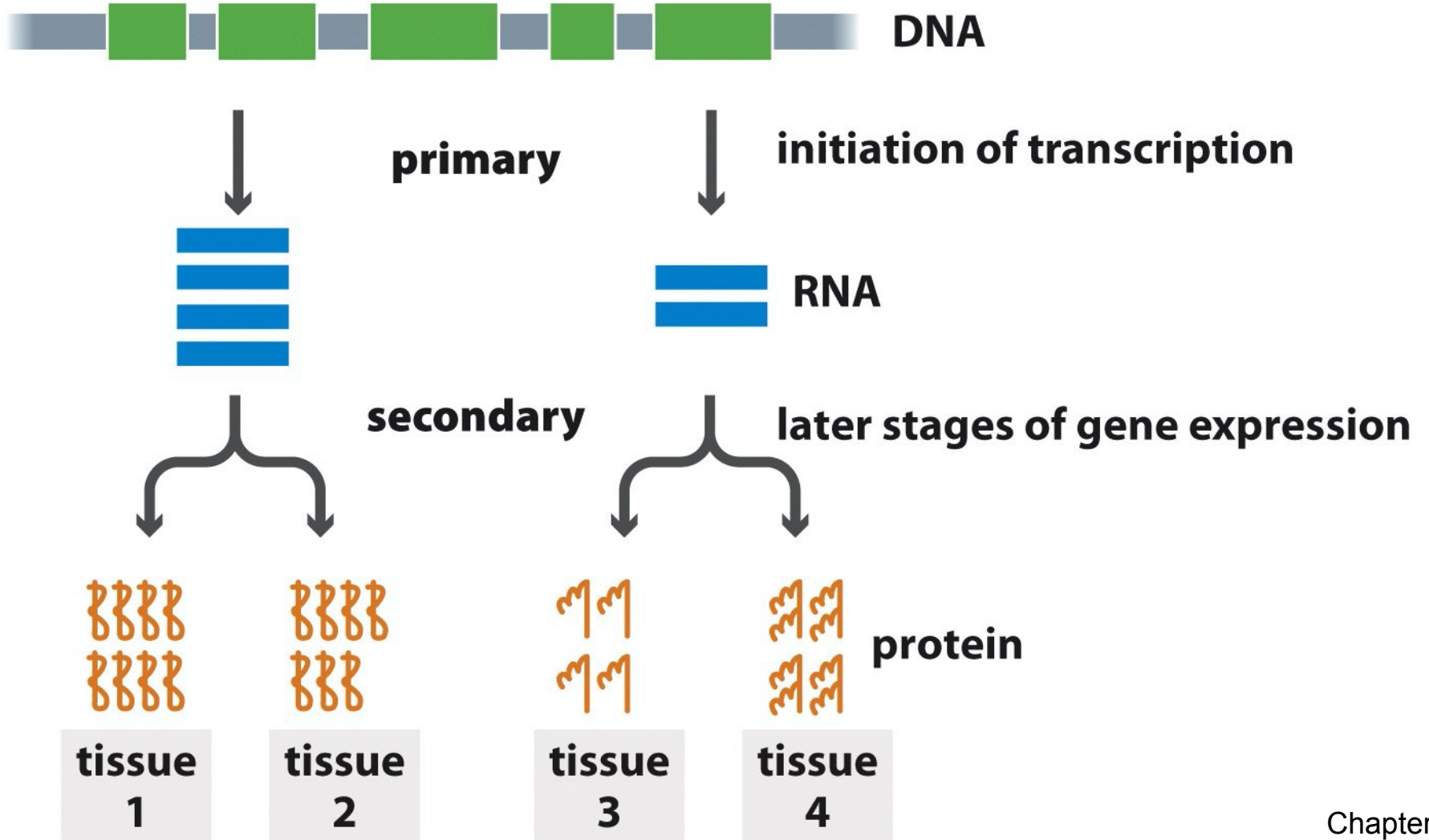
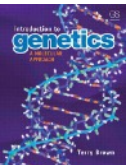


Figure 9.5 Introduction to Genetics (© Garland Science 2012)



1. Transcriptional control

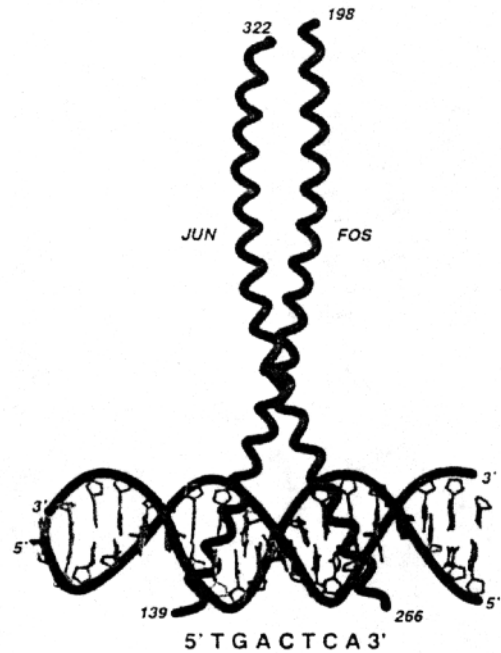
- Transcription control is achieved by molecular/genetic switches.
- Genetic switches that control transcription are composed of:
 1. **DNA motif:** specific DNA sequence that gets recognized by specific regulatory proteins.
 2. **Proteins:** proteins that binds to specific DNA sequence to affect transcription.

1. Transcriptional control – DNA motif

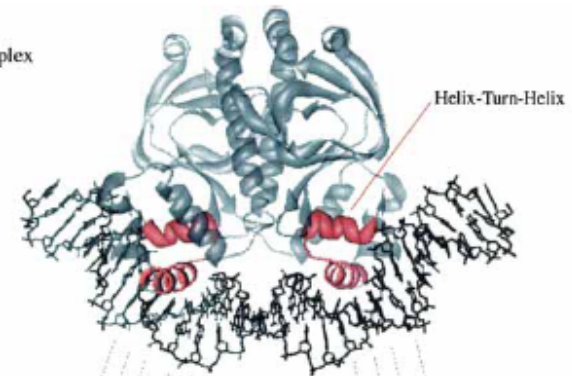


- The DNA motif size and nucleotide composition depends on the protein that is associated.
- Each class of proteins has a general motif structure and sequence.
- The motif sequence is specific and **NOT** every regulatory protein can recognize it.

1. Transcriptional control – DNA motif



A CAP-DNA Complex



B CAP recognition site DNA Logo

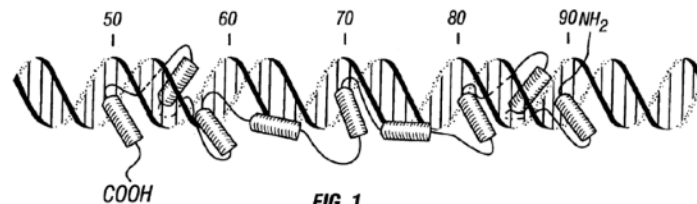
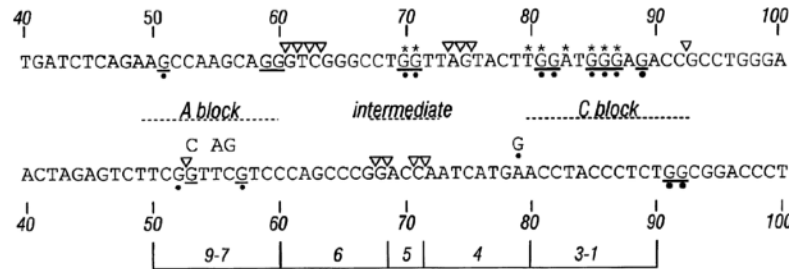


FIG. 1

1. Transcriptional control – regulatory proteins

Regulatory proteins belong to multiple classes.

The different classes have specific protein structure and recognizes specific motifs.

Regulatory proteins:

Helix turn helix

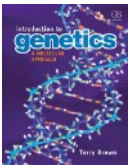
Helix loop helix

Leucine zipper

Zinc fingers

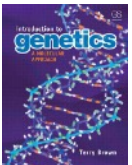
RESEARCH BRIEFING 9.1 PROTEINS THAT BIND TO DNA

- DNA-binding proteins have special structures that enable them to interact with the double helix
- Binding proteins can also make nonspecific attachments with DNA molecules
- Many DNA-binding proteins are dimers

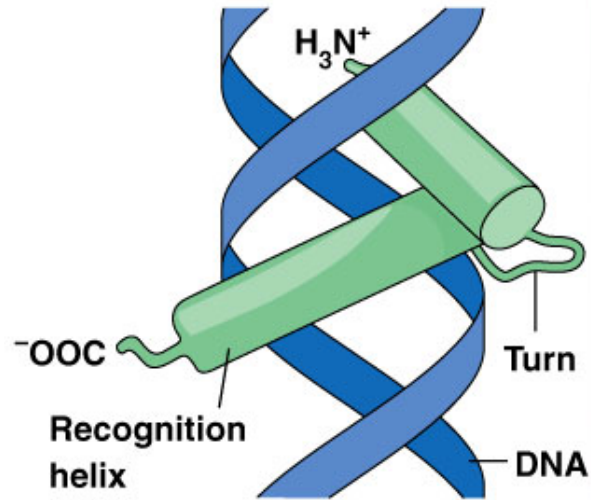
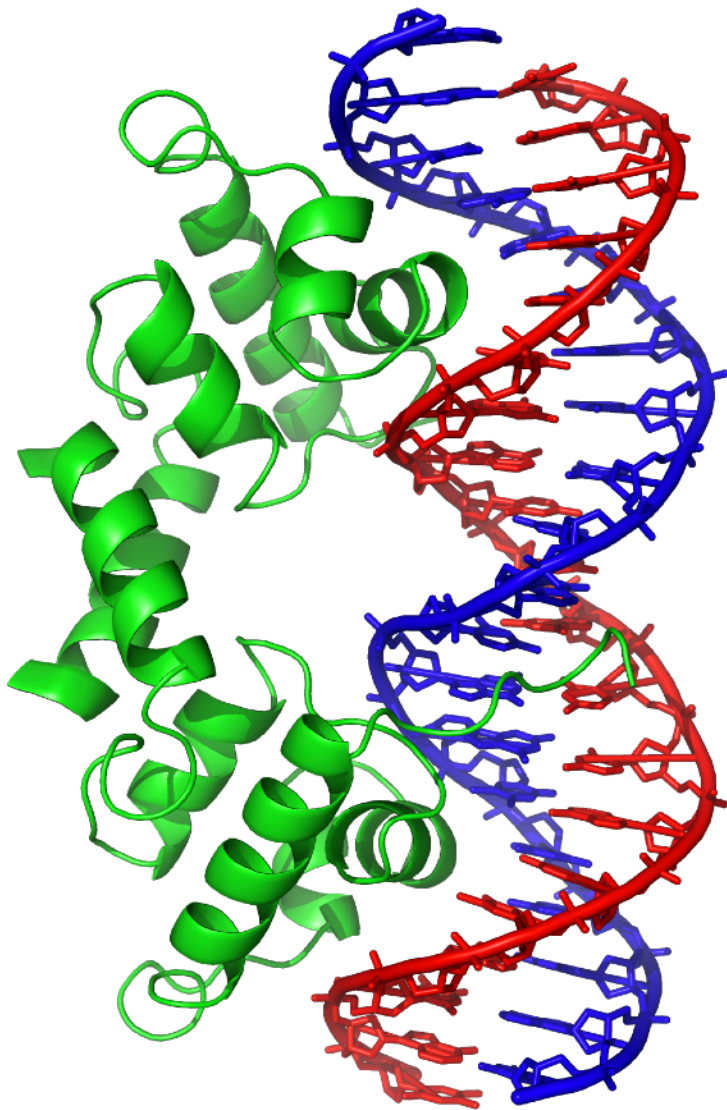


RESEARCH BRIEFING 9.1 PROTEINS THAT BIND TO DNA

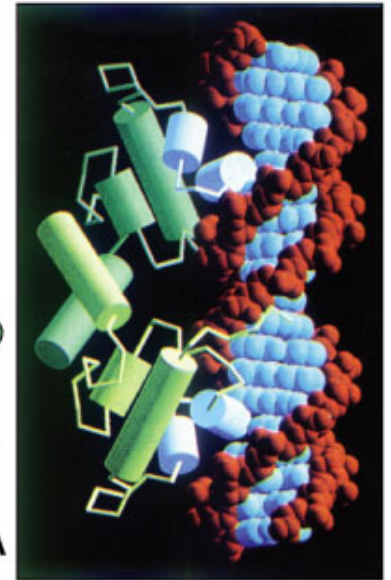
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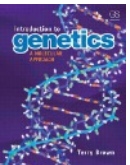
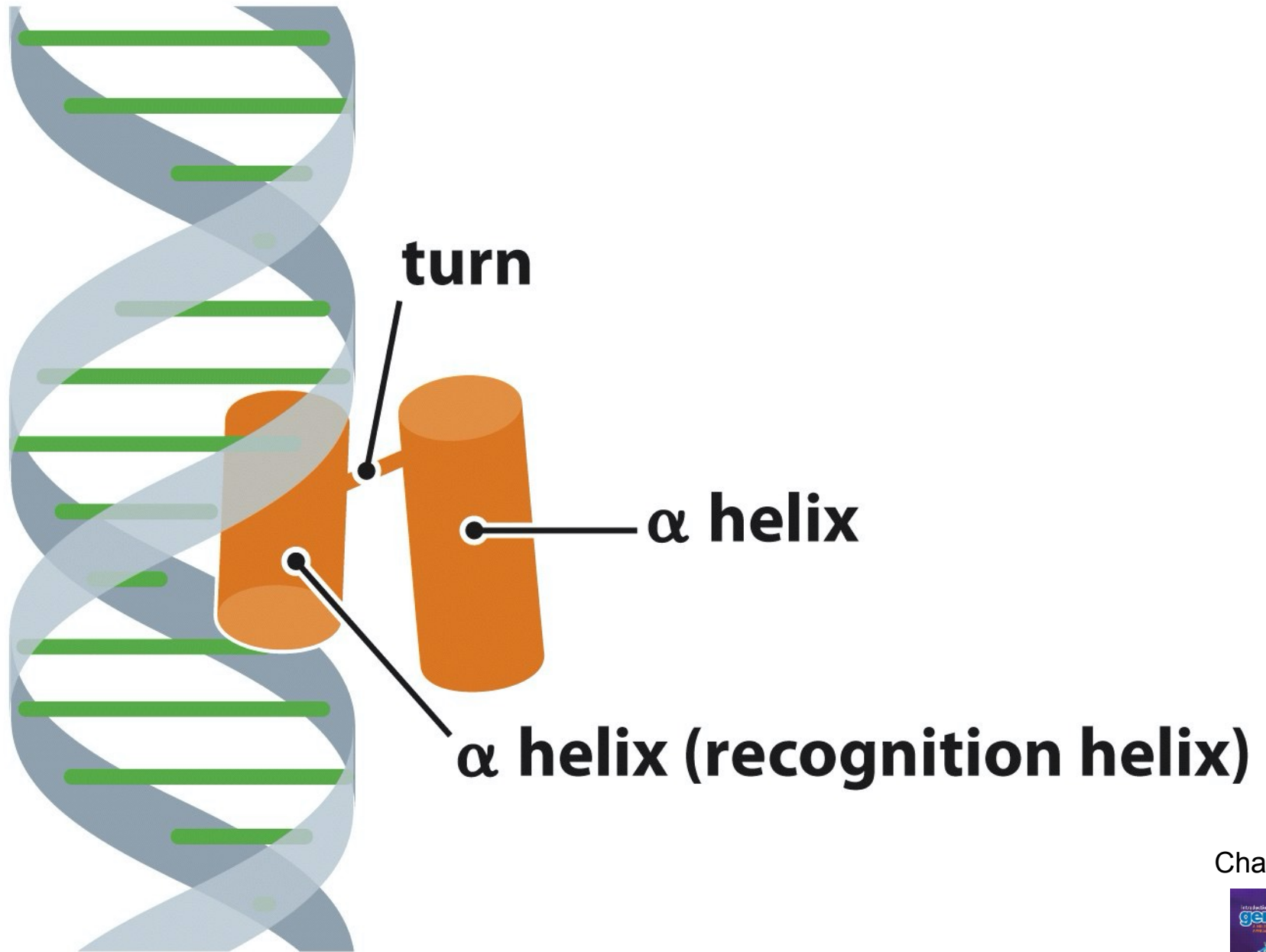
Switch 1: helix turn helix + motif



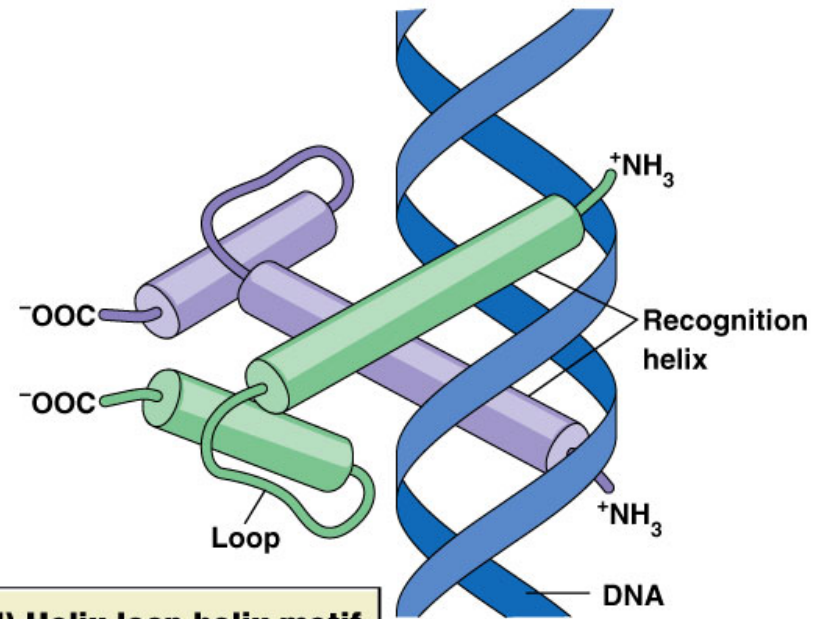
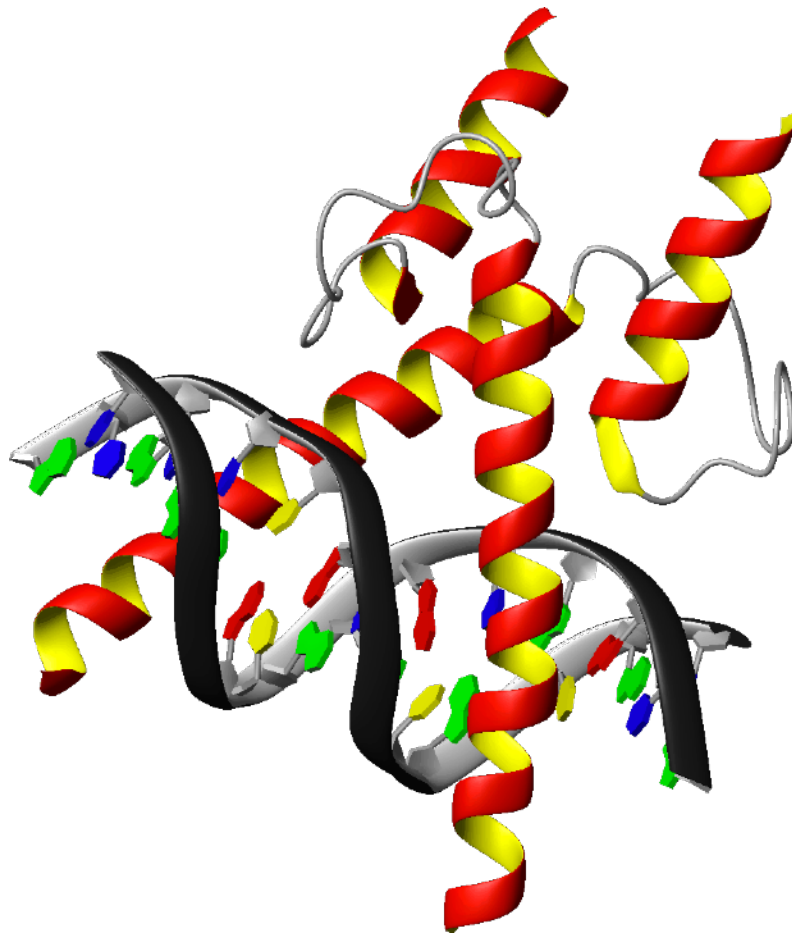
(a) Helix-turn-helix motif



Phage λ repressor bound to DNA

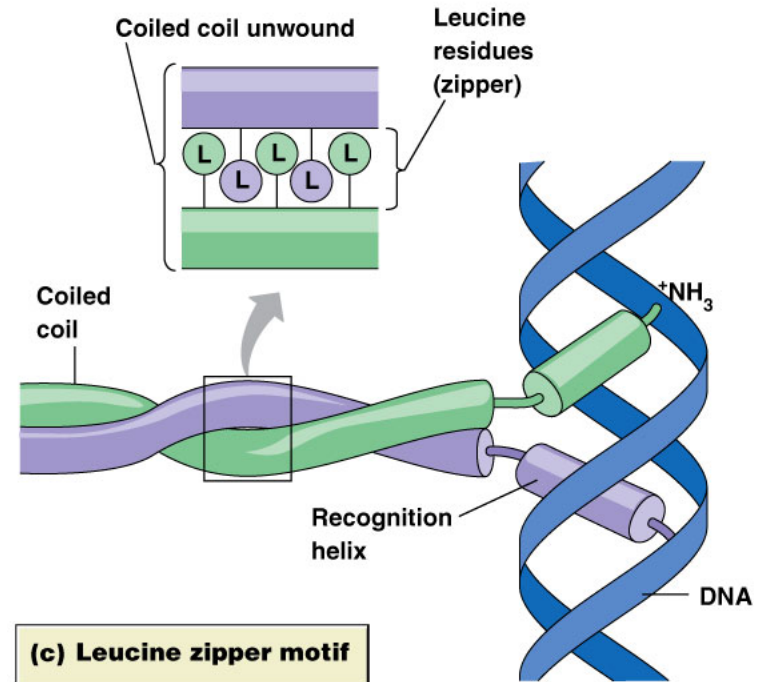
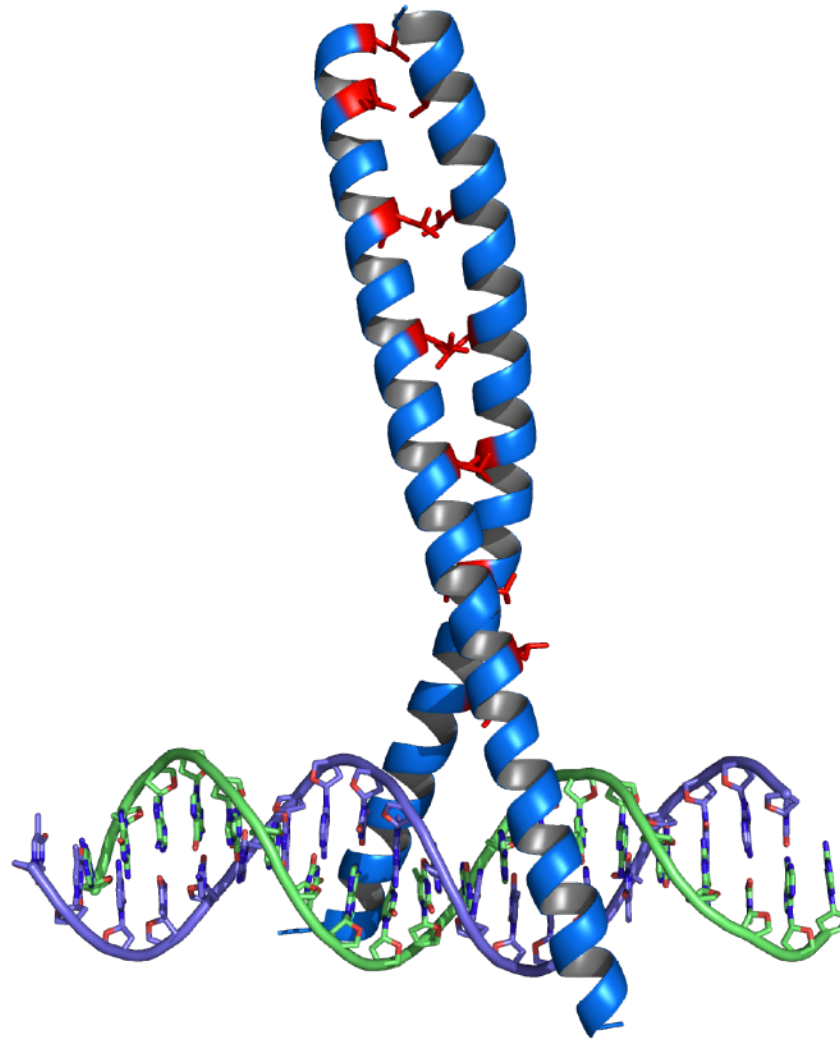


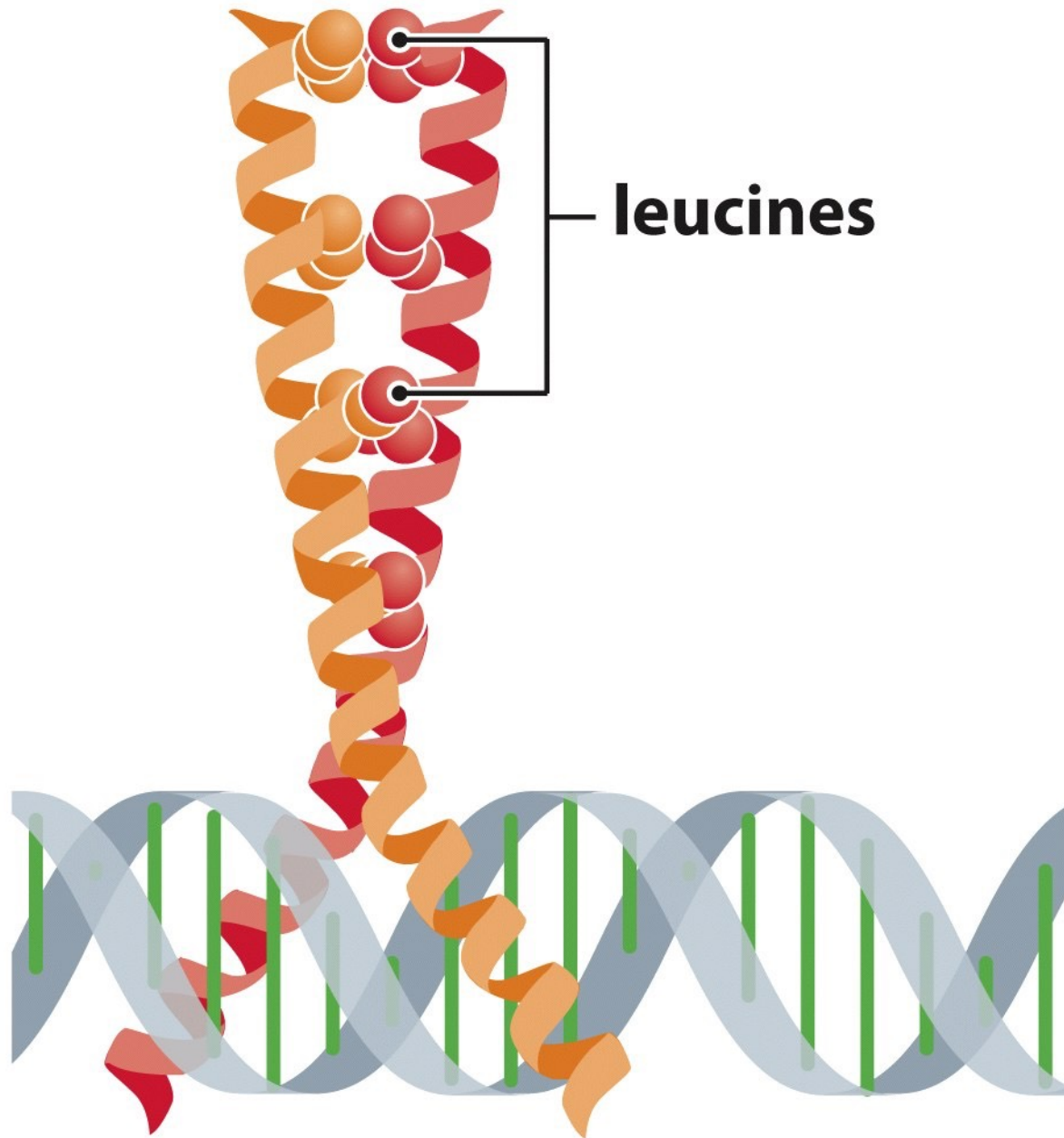
Switch 2: helix loop helix + motif



(d) Helix-loop-helix motif

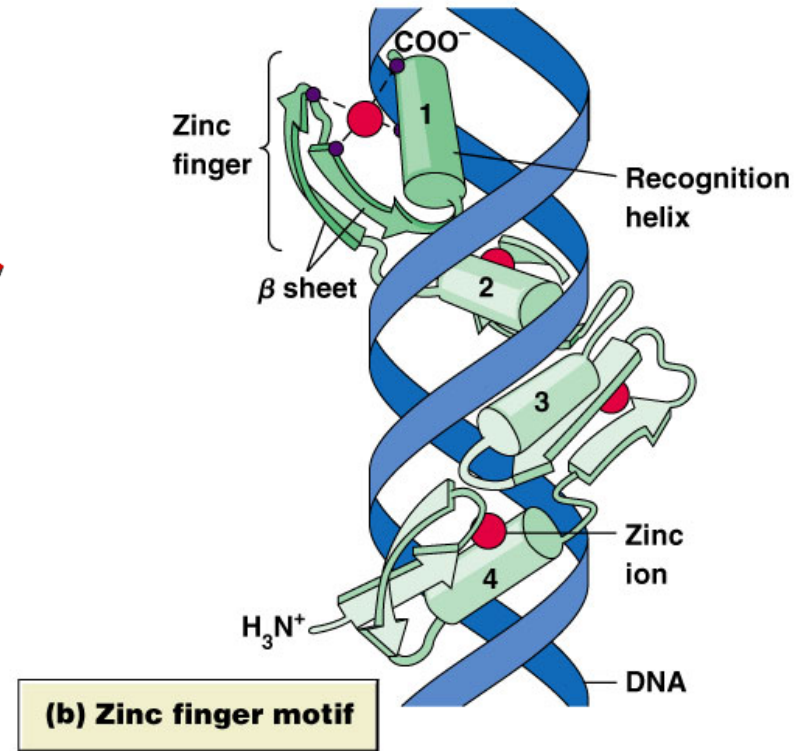
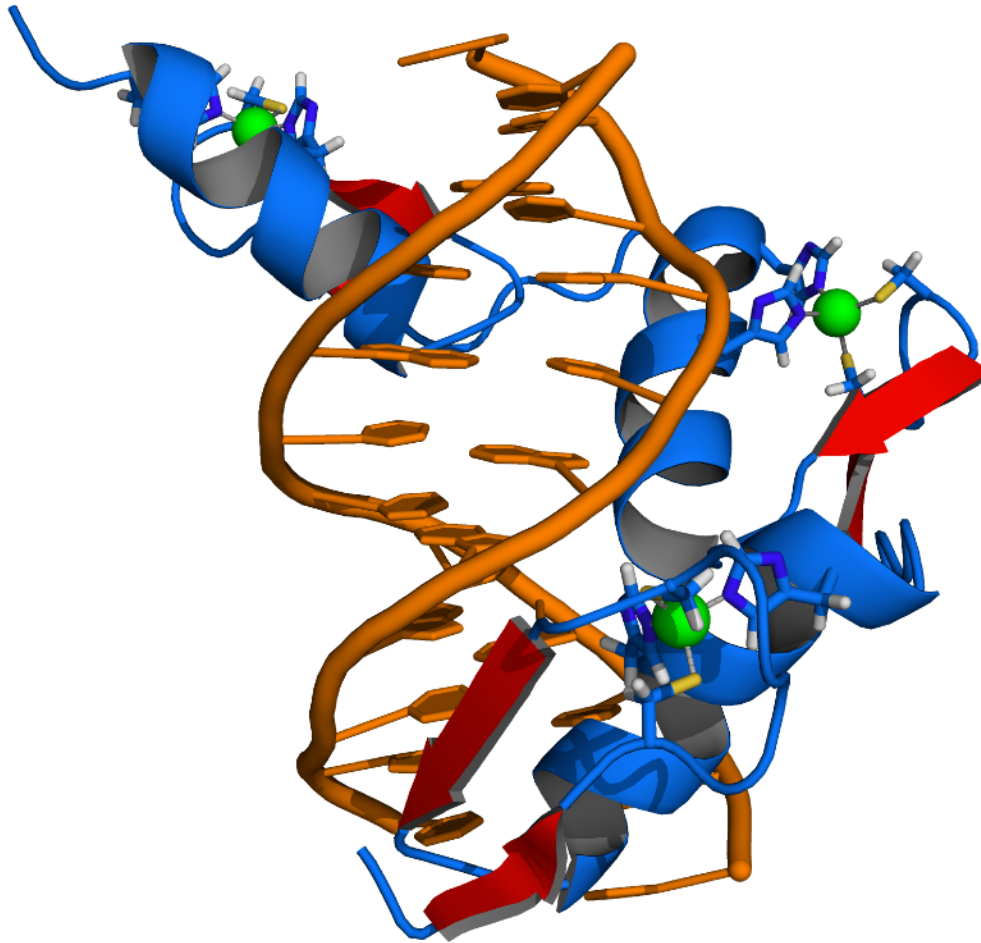
Switch 3: Leucine zipper + motif

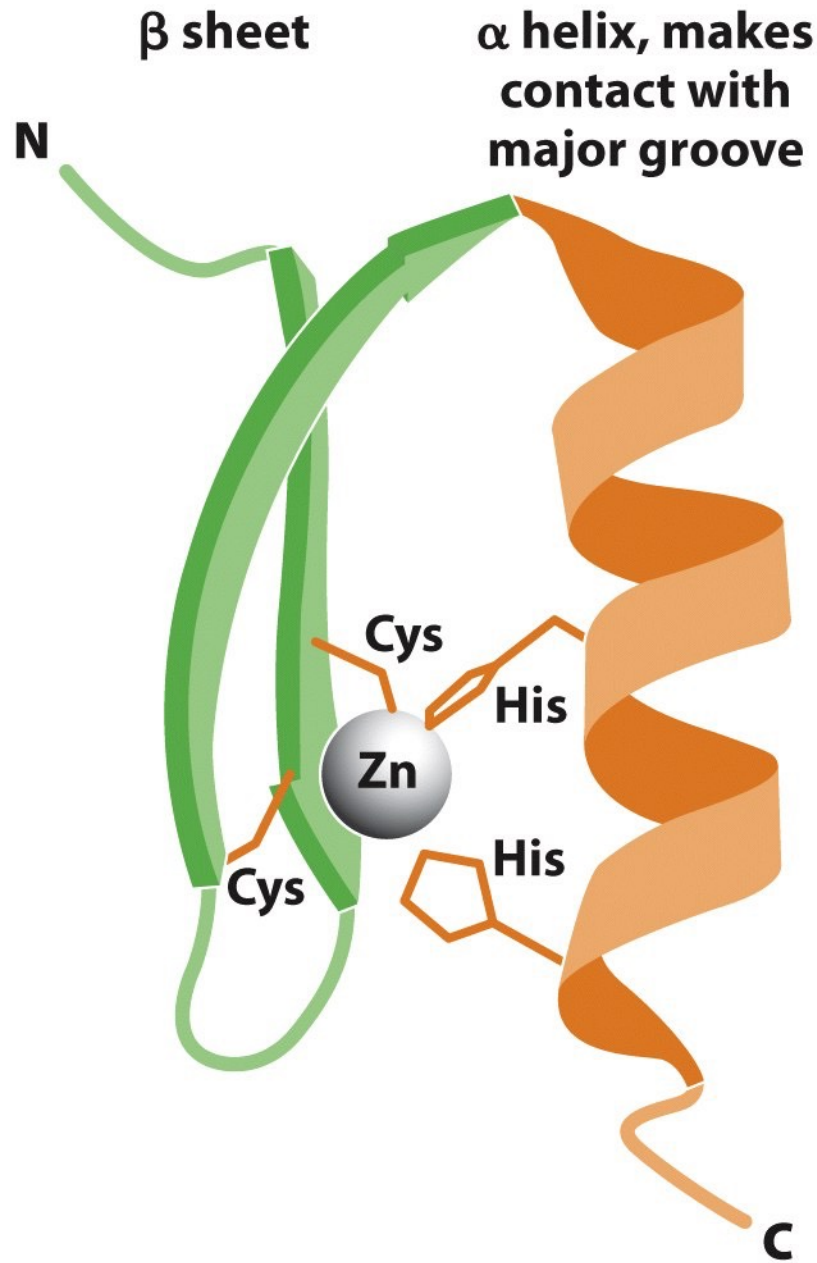




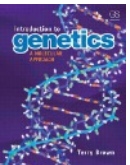
Research Briefing 9.1 Figure 3 Introduction to Genetics (© Garland Science 2012)

Switch 4: Zinc finger + motif



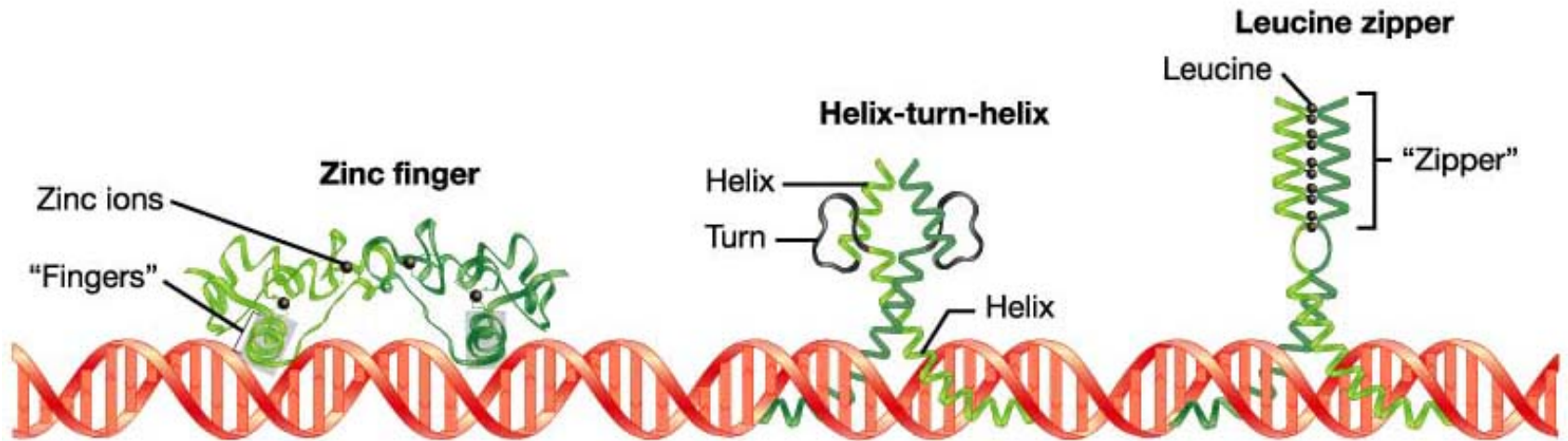


Research Briefing 9.1 Figure 2 Introduction to Genetics (© Garland Science 2012)



Summary

- Regulatory proteins recognizes specific regions near the gene.
- The binding of the regulatory proteins to the DNA motif may turn gene on or off and thus fulfilling its purpose as a genetic switch.



To know

How cells differ in shape, size, and function?

Cell differentiation depends on?

Transcription control

Translation control

Helix-turn-helix

Cloning experiment

RNA transport and localization control

RNA processing control

Zinc finger

Helix-loop-helix

Regulated genes

Constitutive genes

Leucine zipper

Housekeeping genes

Regulatory proteins

DNA motif

mRNA degradation control

Protein activity control



Expectations

- You know the significance of gene expression control for cells/organisms.
- You know the places where control of gene expression can take place.
- You know the DNA motifs and the different classes of regulatory proteins.

For a smile



**READ THE SYLLABUS. READ THE SYLLABUS.
READ THE SYLLABUS. READ THE SYLLABUS.
READ THE SYLLABUS. READ THE SYLLABUS.**