

**Big Idea 3: Living  
systems store, retrieve,  
transmit and respond  
to information essential  
to life processes.**

Enduring understanding 3.B:  
Expression of genetic information  
involves cellular and molecular  
mechanisms.

Essential knowledge 3.B.1: Gene regulation results in differential gene expression, leading to cell specialization.

a. Both DNA regulatory sequences, regulatory genes, and small regulatory RNAs are involved in gene expression.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription.

To foster student understanding of this concept, instructors can choose an illustrative example such as:

- Promoters • Terminators • Enhancers

2. A regulatory gene is a sequence of DNA encoding a regulatory protein or RNA.

Essential knowledge 3.B.1: Gene regulation results in differential gene expression, leading to cell specialization.

b. Both positive and negative control mechanisms regulate gene expression in bacteria and viruses.

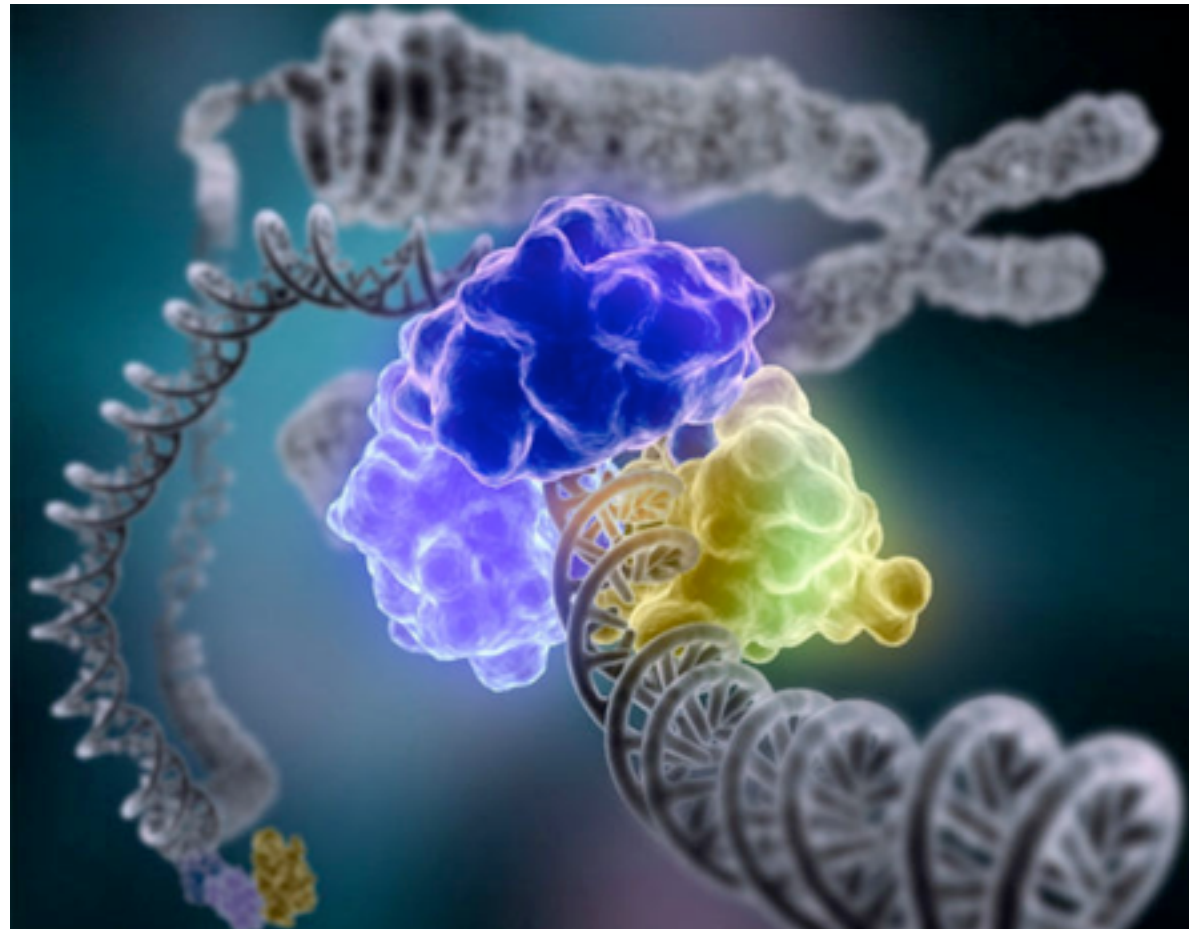
Evidence of student learning is a demonstrated understanding of each of the following:

1. The expression of specific genes can be turned on by the presence of an inducer.
2. The expression of specific genes can be inhibited by the presence of a repressor.
3. Inducers and repressors are small molecules that interact with regulatory proteins and/or regulatory sequences.
4. Regulatory proteins inhibit gene expression by binding to DNA and blocking transcription (negative control).
5. Regulatory proteins stimulate gene expression by binding to DNA and stimulating transcription (positive control) or binding to repressors to inactivate repressor function.
6. Certain genes are continuously expressed; that is, they are always turned “on,” e.g., the ribosomal genes.



# Molecular Basis of Inheritance

I. Main Idea: Bacteria often respond to environmental change by regulating transcription.



# Regulating Gene Expression

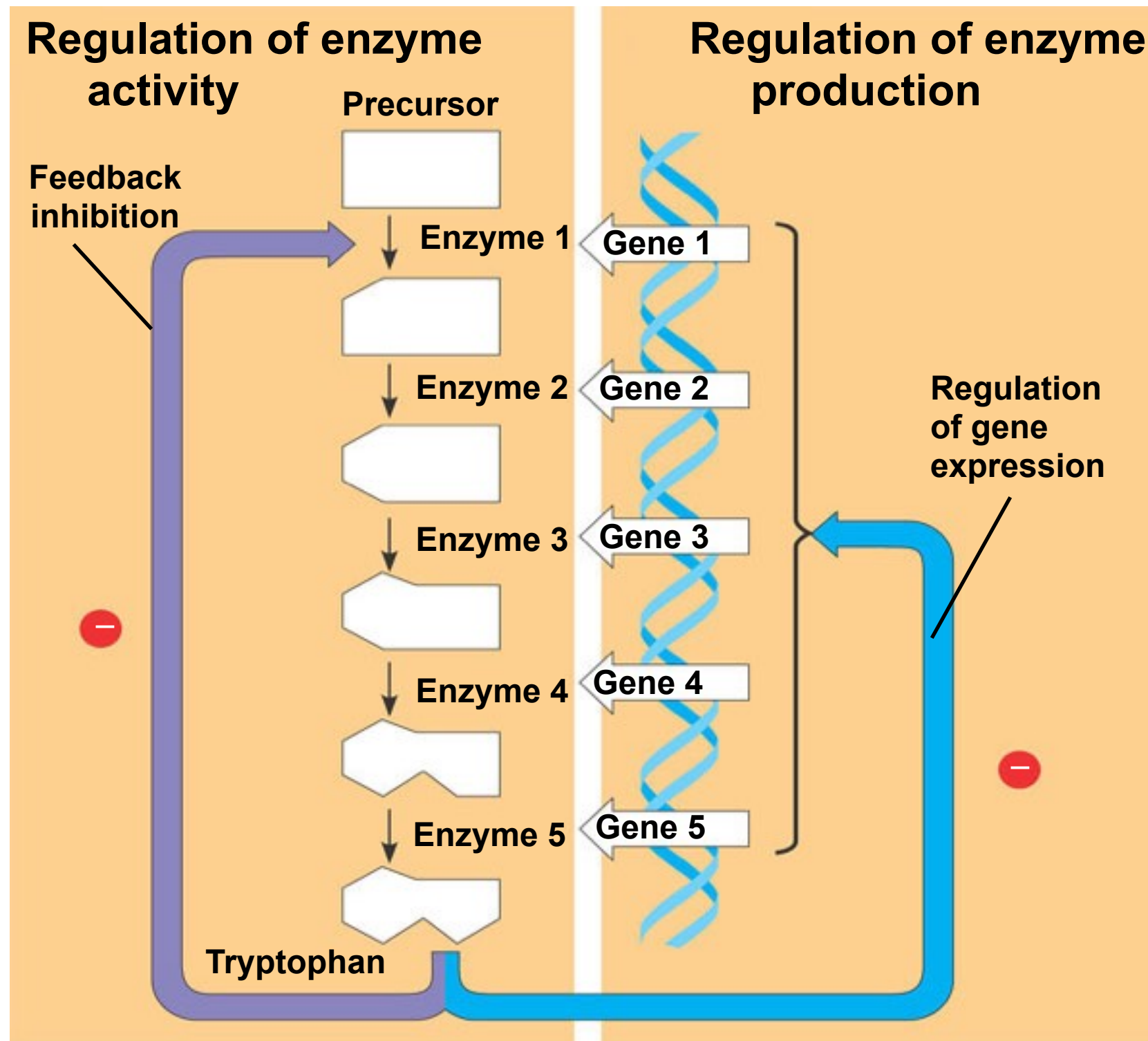
- A cell's genome consists of all its genes.
- NOT ALL genes need to be expressed at ALL times.
- ONLY certain genes are expressed at certain times.
- Bacteria turn on and turn off genes in response to the environmental conditions.
- As environmental conditions change so to does gene expression.

# Regulating Gene Expression

- A bacteria that can turn its genes on and off in response to environmental changes **will save both resources and energy over time.**
- Natural selection has favored these bacteria over those which have less control.
- *Consider E-coli that live in a human colon, if human meal includes a particular nutrient then they need not produce it (save energy ) BUT if human meal does not include a particular nutrient then they need produce it.*
- This fundamentally requires that the E-coli turn on/ off certain genes depending on the presence/ absence of a particular nutrient.

# How are bacterial genes controlled?

“order from the bakery case”

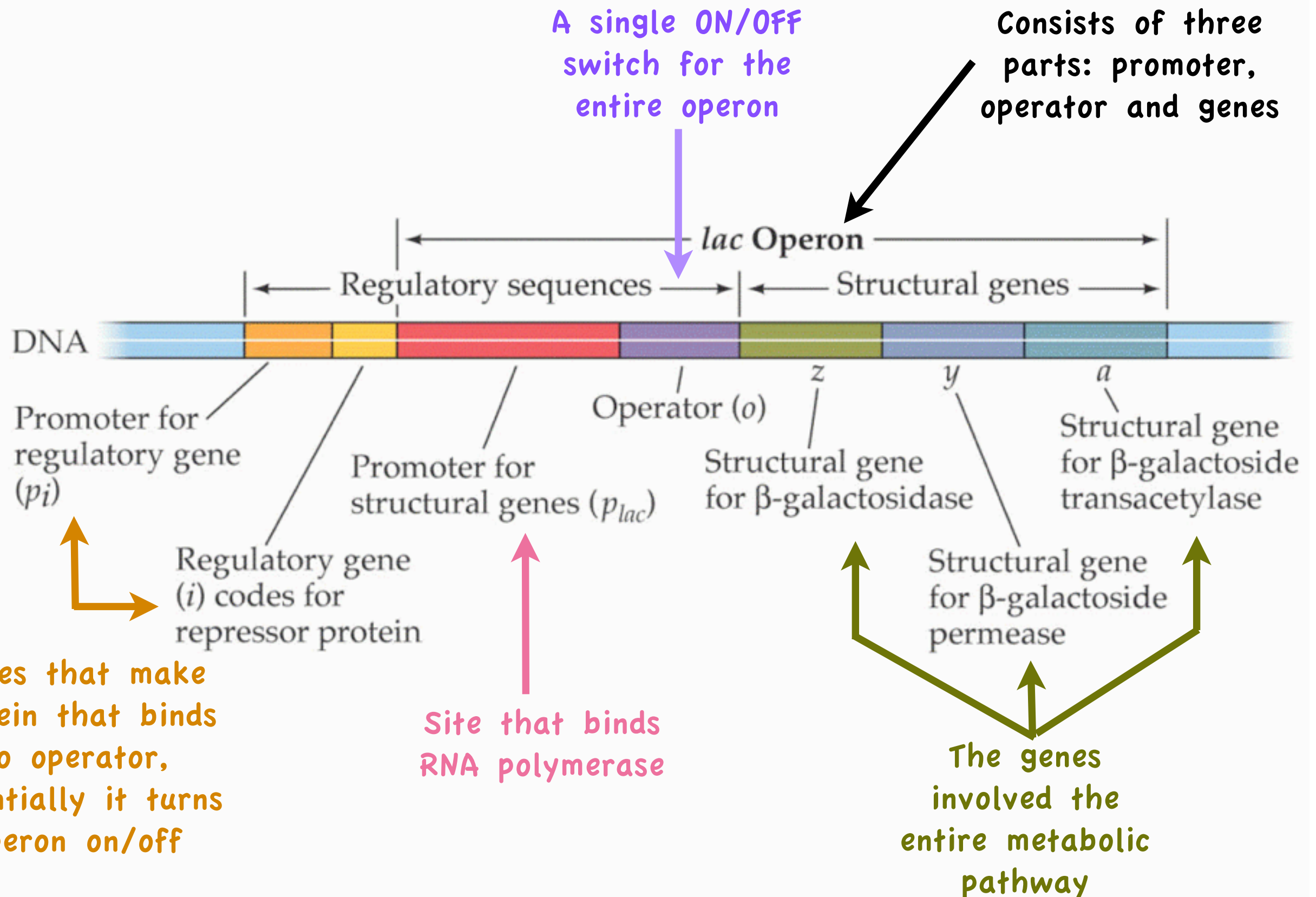


“place a custom order”

“two general ways of eliciting a cellular response”

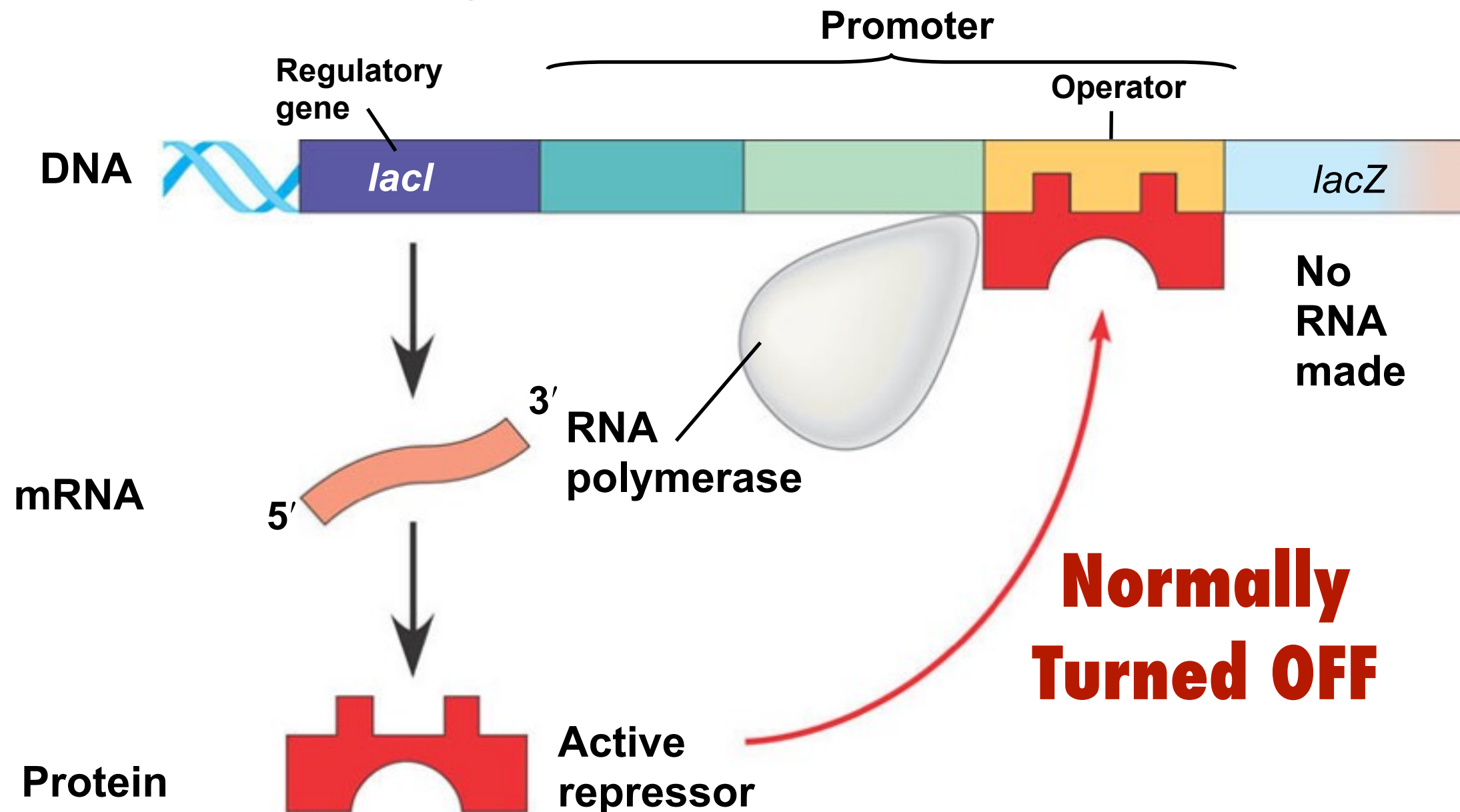


# Bacterial Operon Concept



# Inducible Operons “turn-on-able”

## Negative Gene Regulation

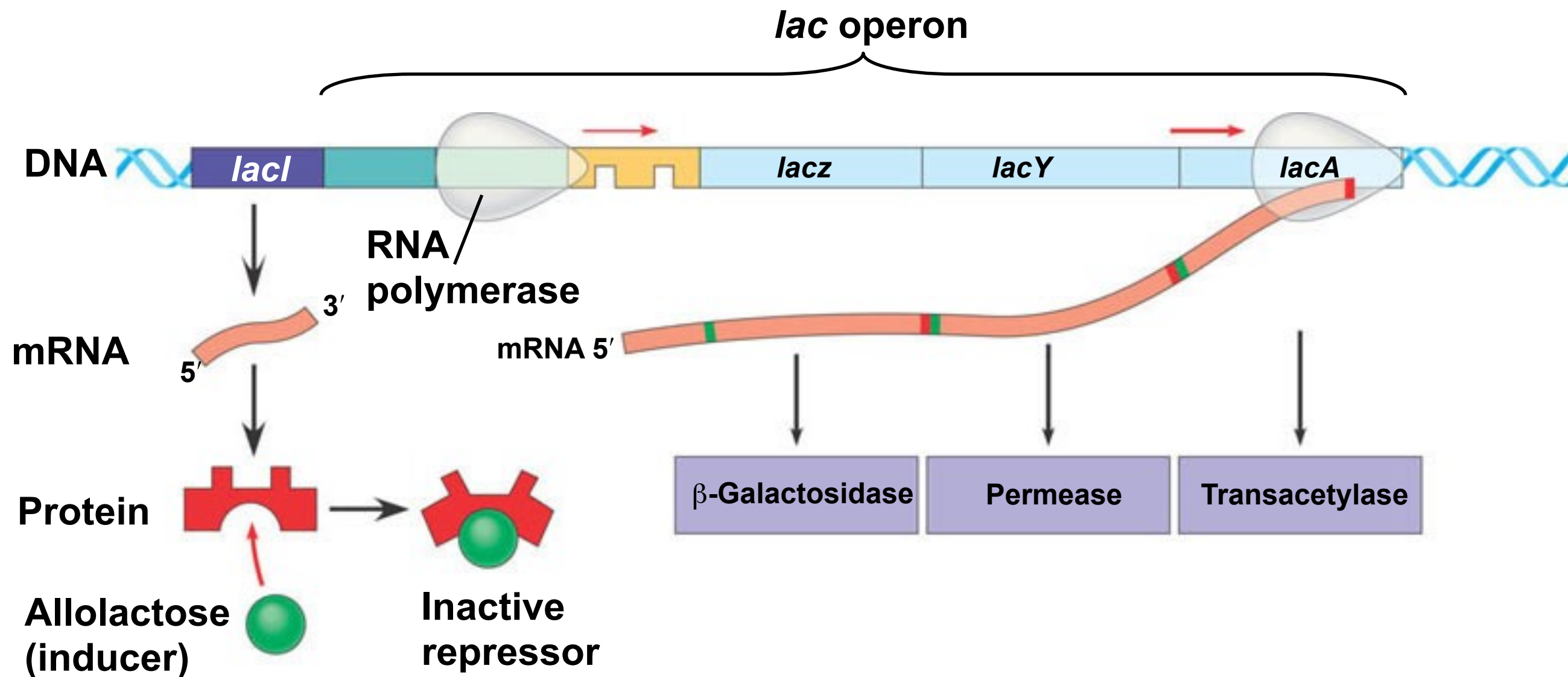


**Lactose absent, repressor active, operon off.** The *lac* repressor is innately active, and in the absence of lactose it switches off the operon by binding to the operator.

# Inducible Operons “turn-on-able”

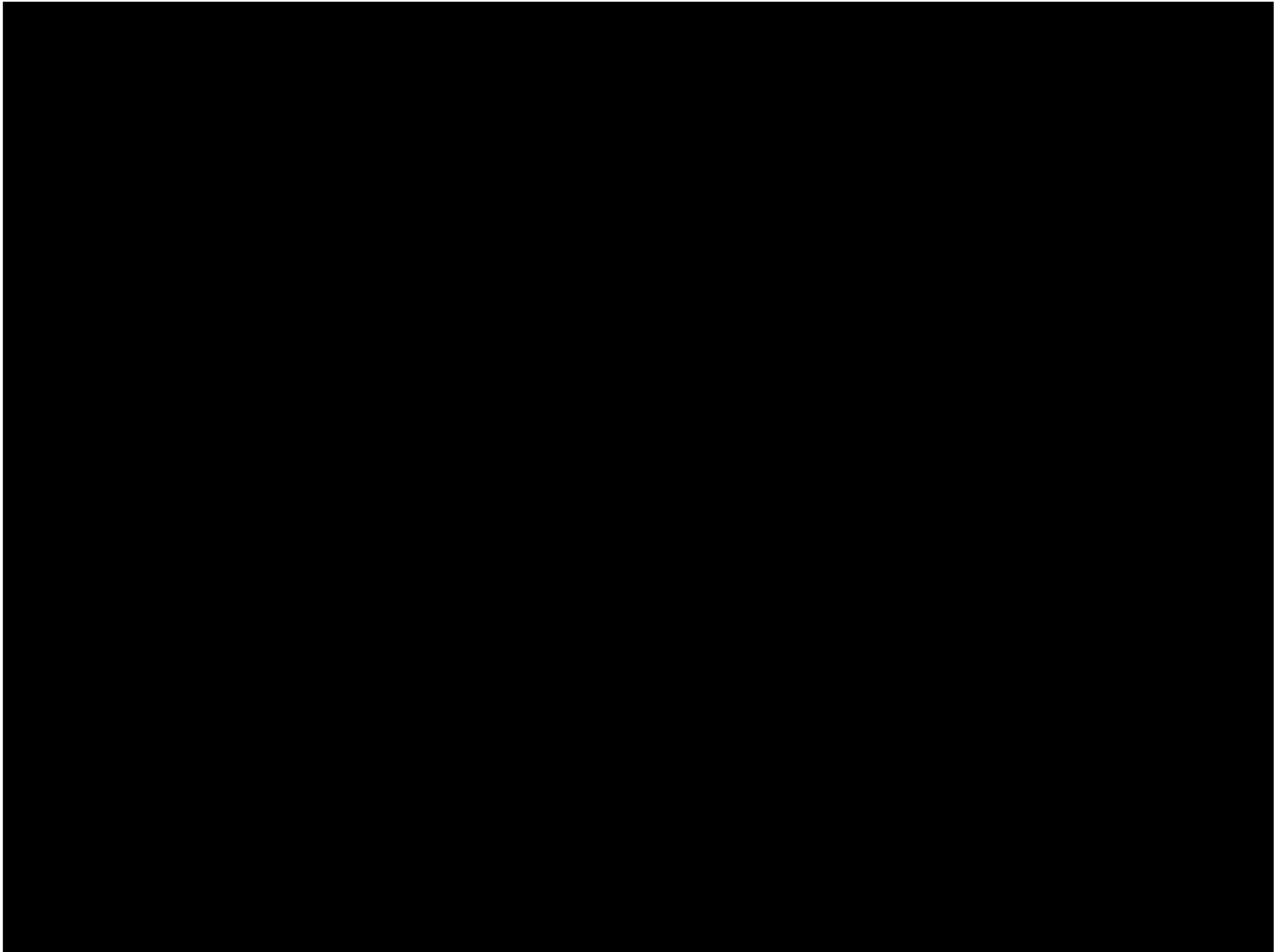
## Negative Gene Regulation

**Normally Turned OFF**



**Lactose present, repressor inactive, operon on.** Allolactose, an isomer of lactose, derepresses the operon by inactivating the repressor. In this way, the enzymes for lactose utilization are induced.

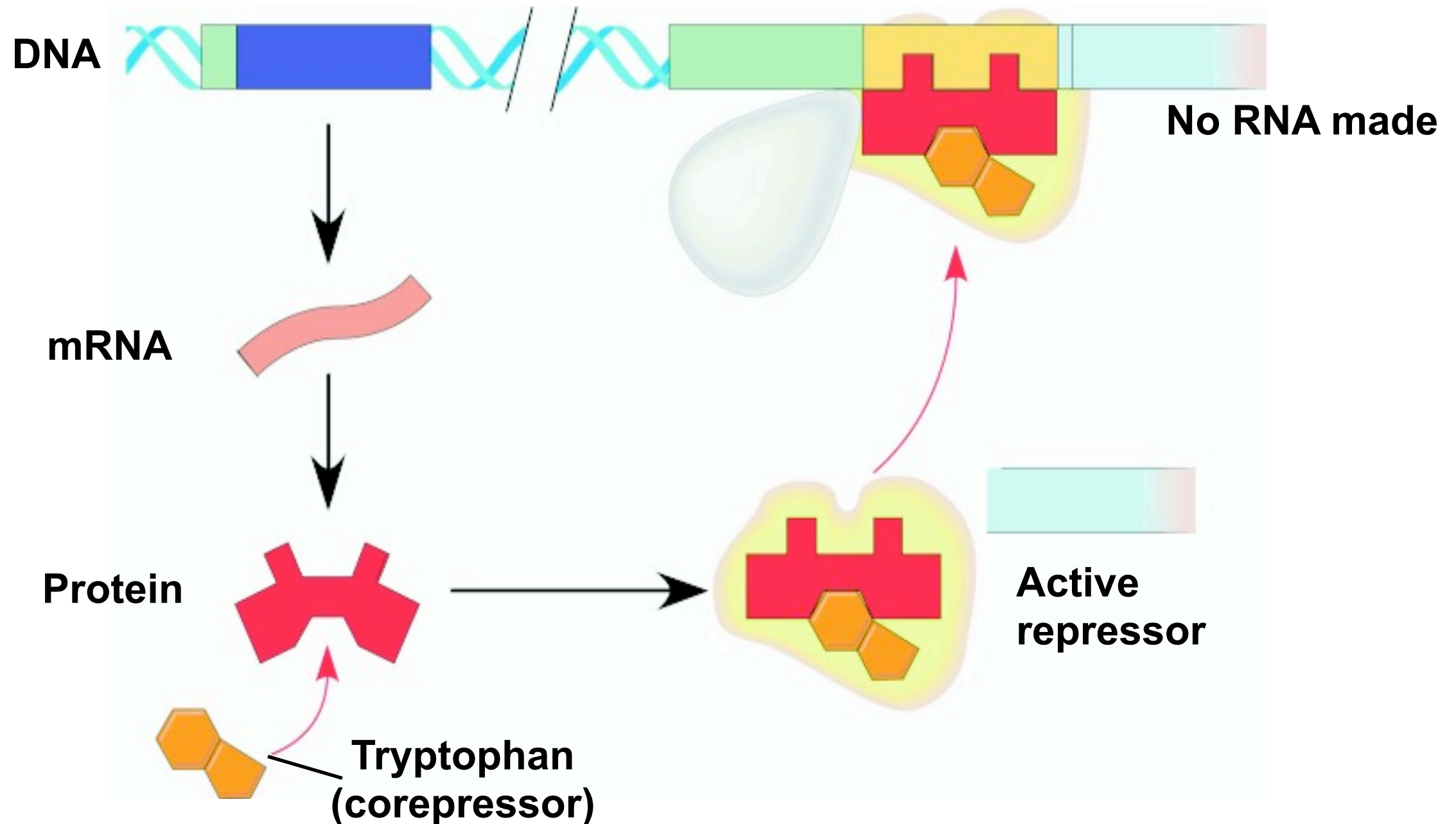
# lac Operons “turn-on-able”



# Repressible Operons “turn-off-able”

## Negative Gene Regulation

**Normally Turned ON**

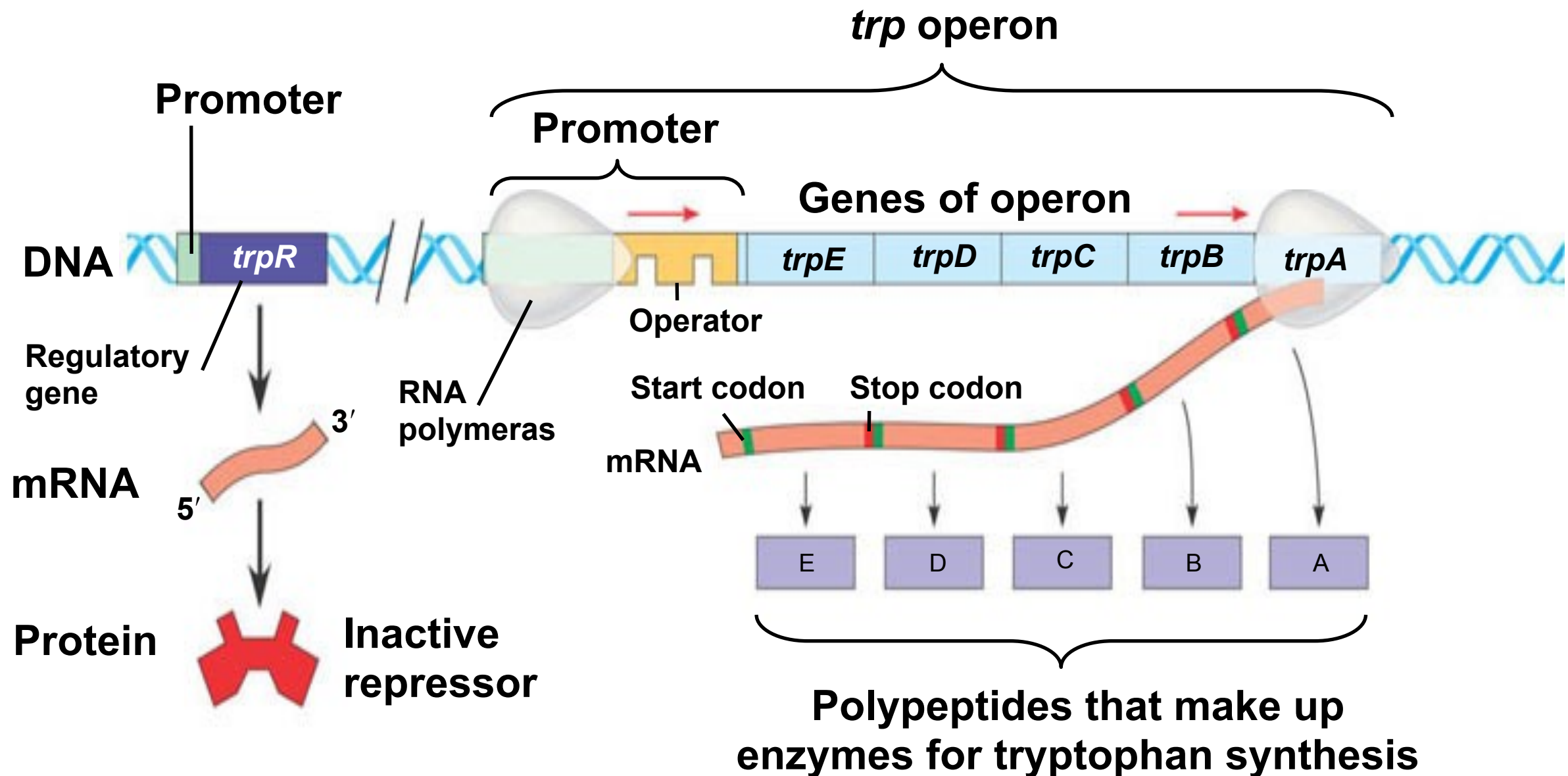


**Tryptophan present, repressor active, operon off. As tryptophan accumulates, it inhibits its own production by activating the repressor protein.**



# Repressible Operons “turn-off-able”

## Negative Gene Regulation **Normally Turned ON**



**Tryptophan absent, repressor inactive, operon on. RNA polymerase attaches to the DNA at the promoter and transcribes the operon's genes.**

# Let's Review so far

- **Inducible Operons (“turn-on-able”)**
  - inducer binds to innately active repressor there by inactivating the repressor and turning operon on
  - usually operates in catabolic pathways
- **Repressible Operons (“turn-off-able”)**
  - repressor binds to innately inactive repressor there by activating the repressor and turning operon off
  - usually operates in anabolic pathways

Essential knowledge 3.B.1: Gene regulation results in differential gene expression, leading to cell specialization.

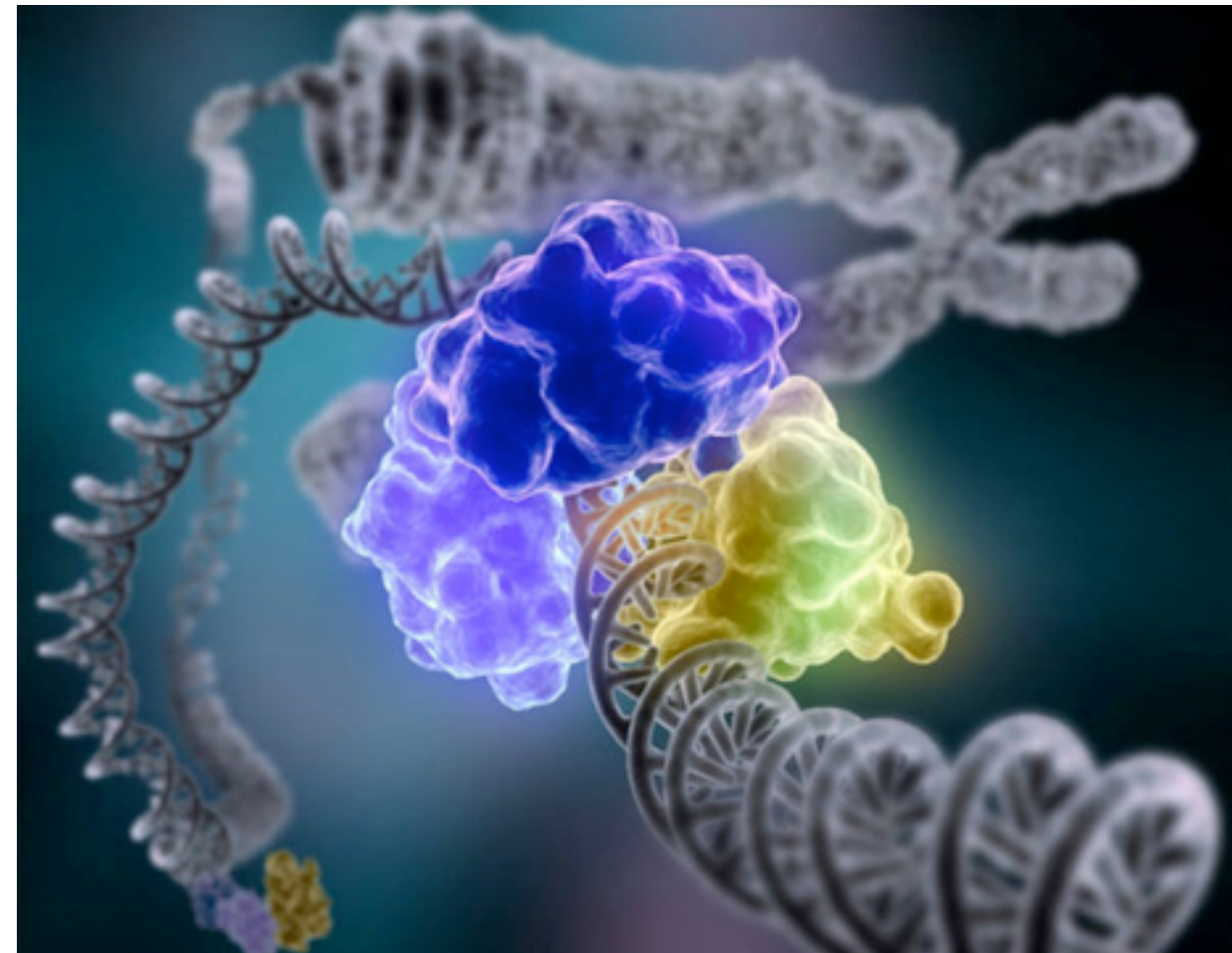
c. In eukaryotes, gene expression is complex and control involves regulatory genes, regulatory elements and transcription factors that act in concert.

Evidence of student learning is a demonstrated understanding of each of the following:

1. Transcription factors bind to specific DNA sequences and/or other regulatory proteins.
2. Some of these transcription factors are activators (increase expression), while others are repressors (decrease expression).
3. The combination of transcription factors binding to the regulatory regions at any one time determines how much, if any, of the gene product will be produced.

# Molecular Basis of Inheritance

Main Idea: Regulating gene expression is also important for eukaryotic cells, especially those that make up a multicellular organism.



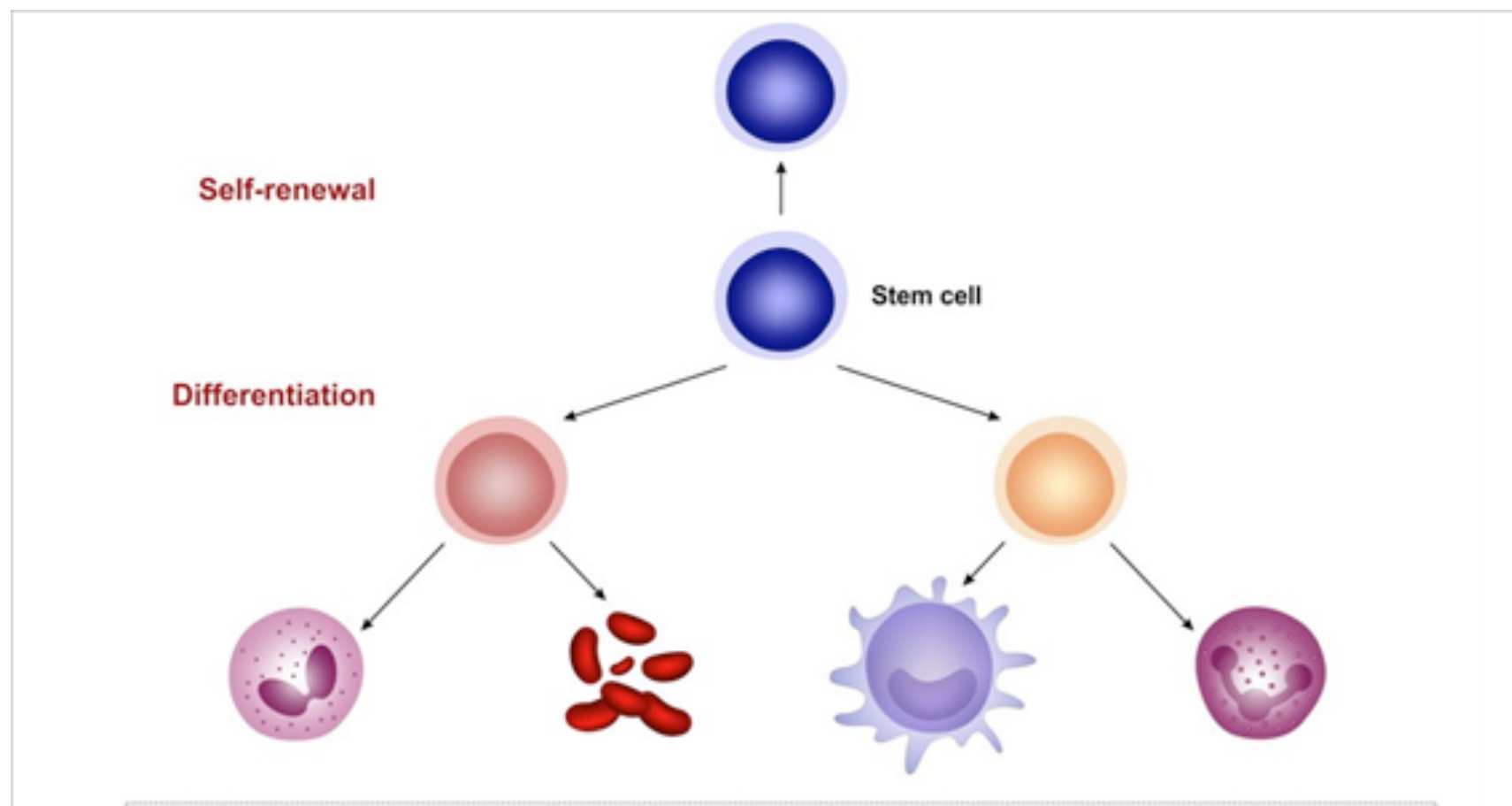
# Differential Gene Expression

- Typical human cells expresses ~20% of its genes at any given time
  - highly differentiated cells like nerve cells even less
- Almost all cells have an identical genome
  - immune cells are an exception
- The difference between cell types are not due to different genes present but to **differential gene expression**, each cell using its own unique combination of genes.

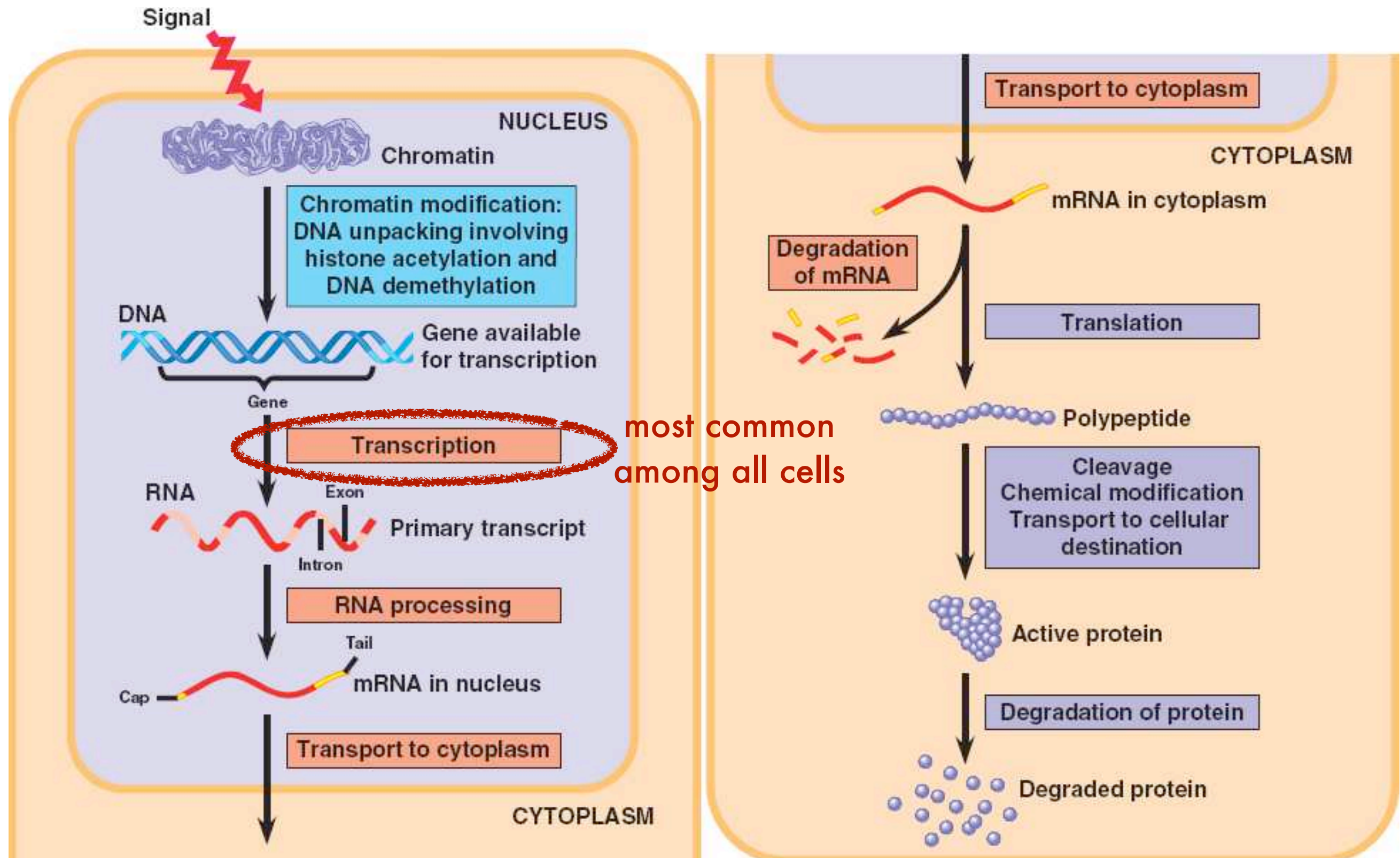


# Differential Gene Expression

- The function of any cell depends on the appropriate set of genes being expressed.
- Transcription factors must locate the “right genes” at the “right time”.
- if this does not occur imbalances and disease can result



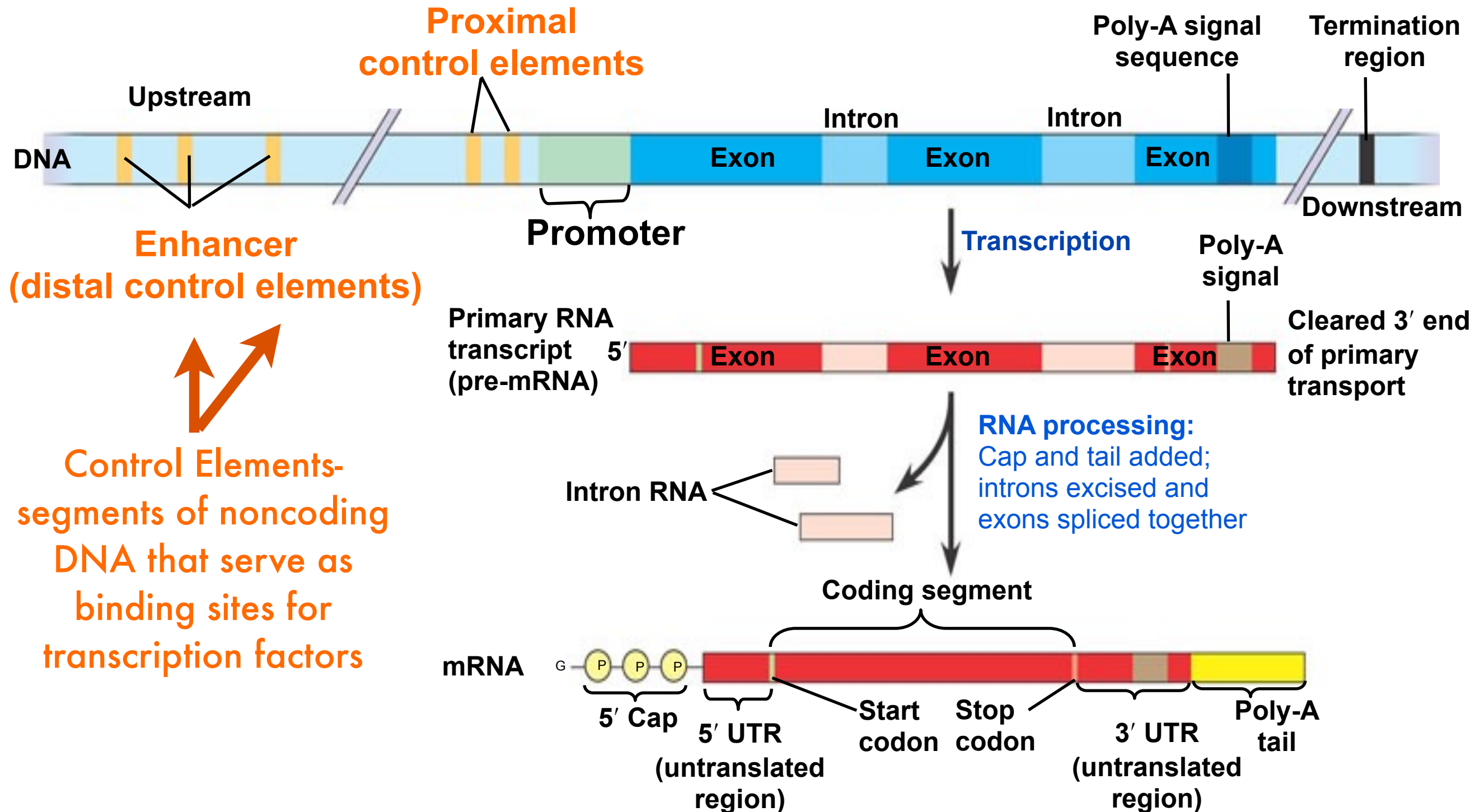
# Differential Gene Expression



# Regulation of Transcription

- The next and most common place to regulate genes occurs at initiation step of transcription.
- This is true in both prokaryotes and eukaryotes!
- Since eukaryotic transcription is more complicated we should start by reviewing the structure of a eukaryotic gene.

- Organization of a Typical Eukaryotic Gene



# Regulation of Transcription

- Roles of Transcription Factors
- Eukaryotes have a sort of volume control when comes to gene expression.
- **General Transcription Factors**, bind to DNA, the promoter and the RNA polymerase (this what you saw in last powerpoint) = **Low Volume**
- **Specific Transcription Factors**, bind to DNA, the promoter, the RNA polymerase and the control elements (seen on the last slide) = **High Volume**



# Regulation of Transcription

- Enhancers & Specific Transcription Factors
- Enhancers can greatly affect the rate of transcription depending upon the type of specific transcription factors.
- **Repressors**, bind to the control elements of the enhancer  
= turn down the Volume (rate of transcription)
- **Activators**, bind to the control elements of the enhancer  
= turn up the Volume (rate of transcription)

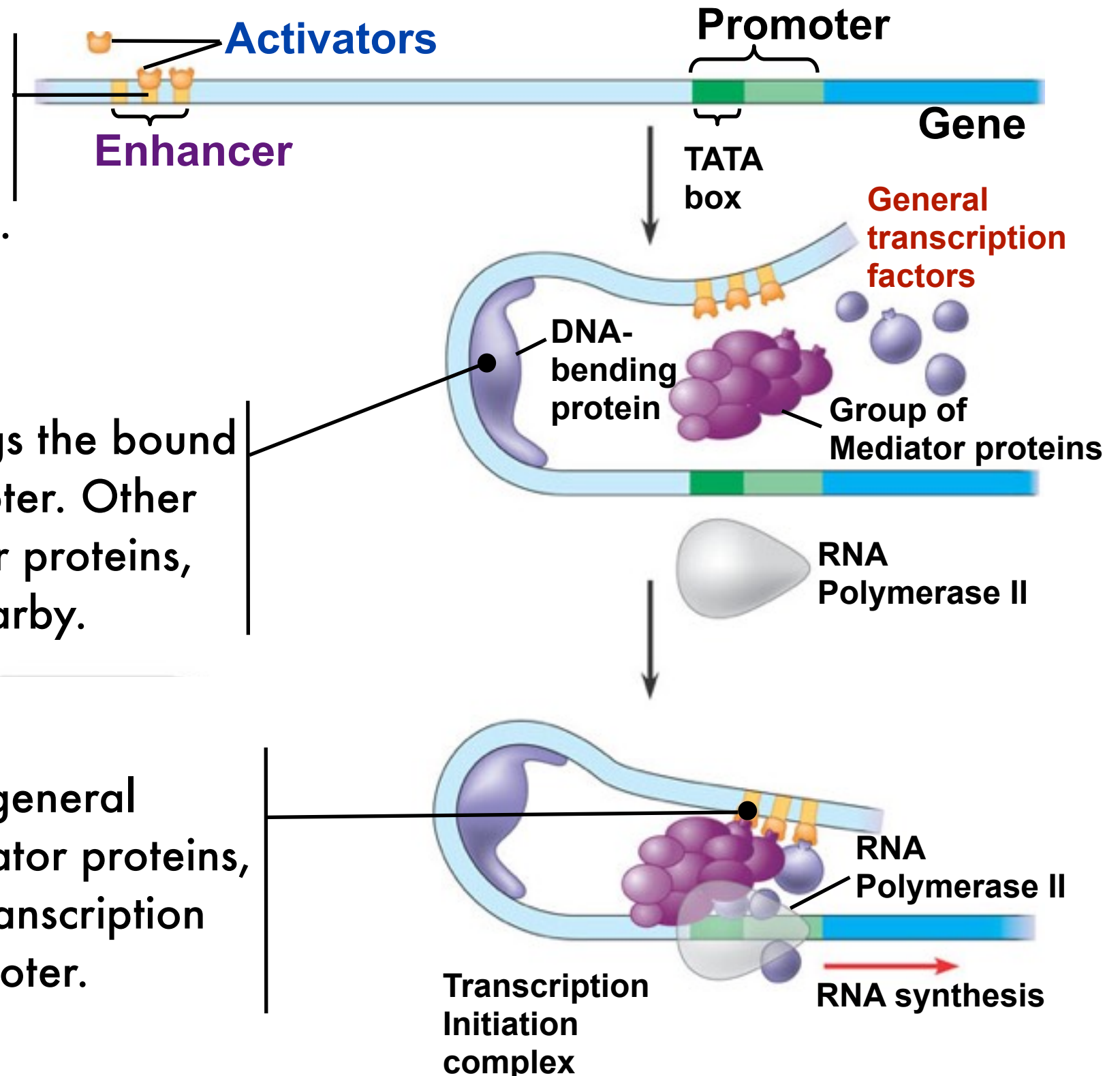
# ● Enhancers & Specific Transcription Factors

Activator proteins bind to distal control elements grouped as an enhancer in the DNA. This enhancer has three binding sites.

A DNA-bending protein brings the bound activators closer to the promoter. Other transcription factors, mediator proteins, and RNA polymerase are nearby.

The activators bind to certain general transcription factors and mediator proteins, helping them form an active transcription initiation complex on the promoter.

Distal control element

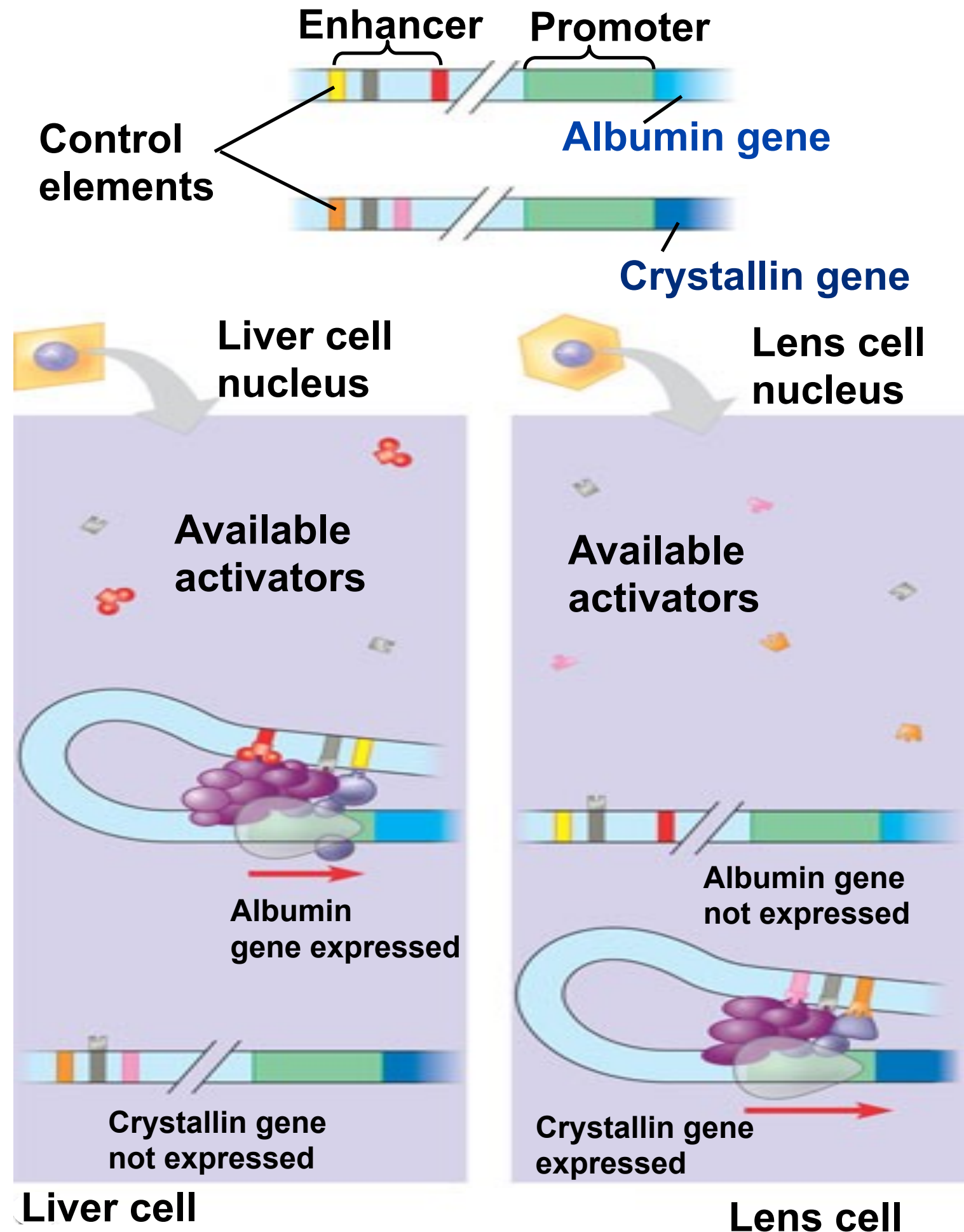


# Regulation of Transcription

- Combinatorial Control of Gene Activation
- In eukaryotes precise control of transcription depends largely on the binding of activators to DNA control elements.
  - With so many genes you might expect a lot of different activators, ironically the number is small.
  - These dozen or so sequences show up again and again in the control elements for different genes.
  - The combination of control elements is the important factor when regulating gene transcription.

- Combinatorial Control of Gene Activation

- Even with only a dozen control elements, a very large number of combinations are possible.



# Regulation of Transcription

- Coordinately Controlled Genes in Eukaryotes
- Recall that prokaryotes clustered all the genes in a metabolic pathway together in one operon so that they might all be expressed at the same time.
- Eukaryotes need to express multiple genes at the same time as well BUT their genes are not placed together, in fact they may not even be found on the same chromosome.

**SO, How do they do it? How do they transcribe all the genes in a metabolic pathway at the same time?**

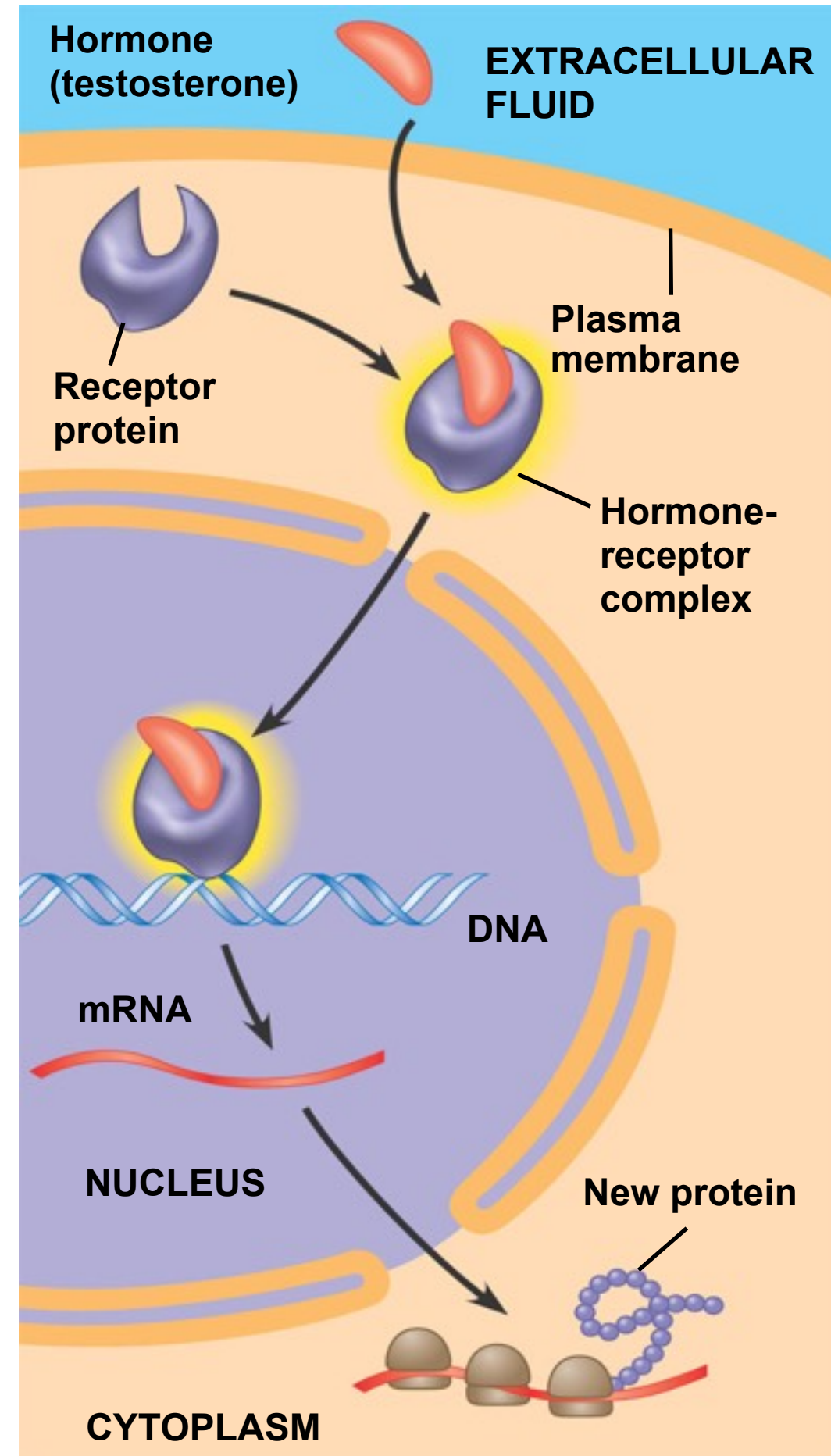


# Regulation of Transcription

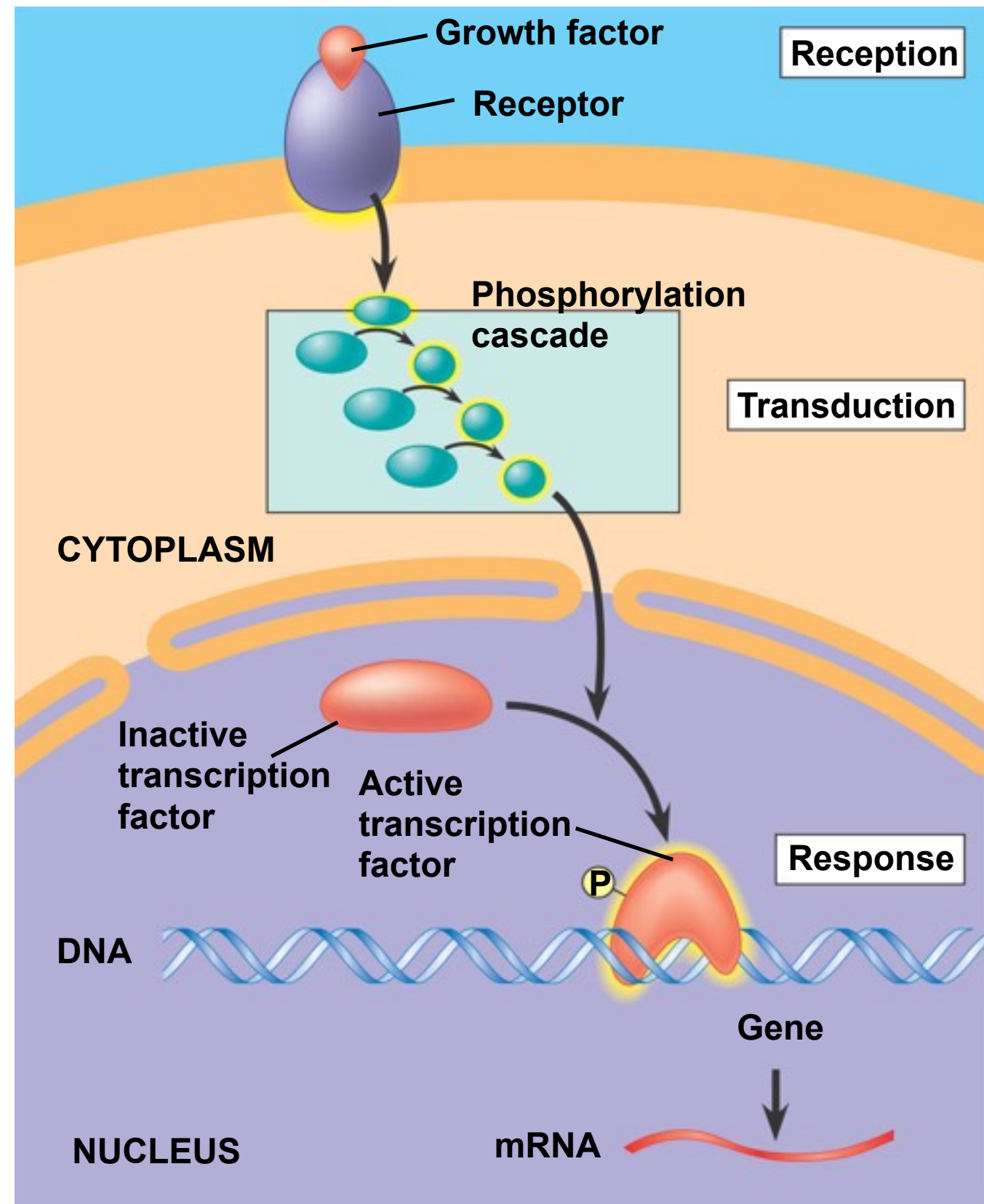
- Coordinately Controlled Genes in Eukaryotes
- Co-expressing genes coding for enzymes in a metabolic pathway depend on the association of a specific combination of control elements with every gene in the group.
- Copies of the activators that recognize the control elements bind to them, promoting the simultaneous transcription of genes regardless of their position in the genome.

- Coordinately Controlled Genes in Eukaryotes
- Steroid hormone enters cell, binds to intracellular receptor which serves as the transcription activator.
- Every gene in the same metabolic pathway is turned on by this same hormone receptor complex.
- Estrogen activates all the genes that stimulate cell division in the uterus, in preparation for pregnancy.

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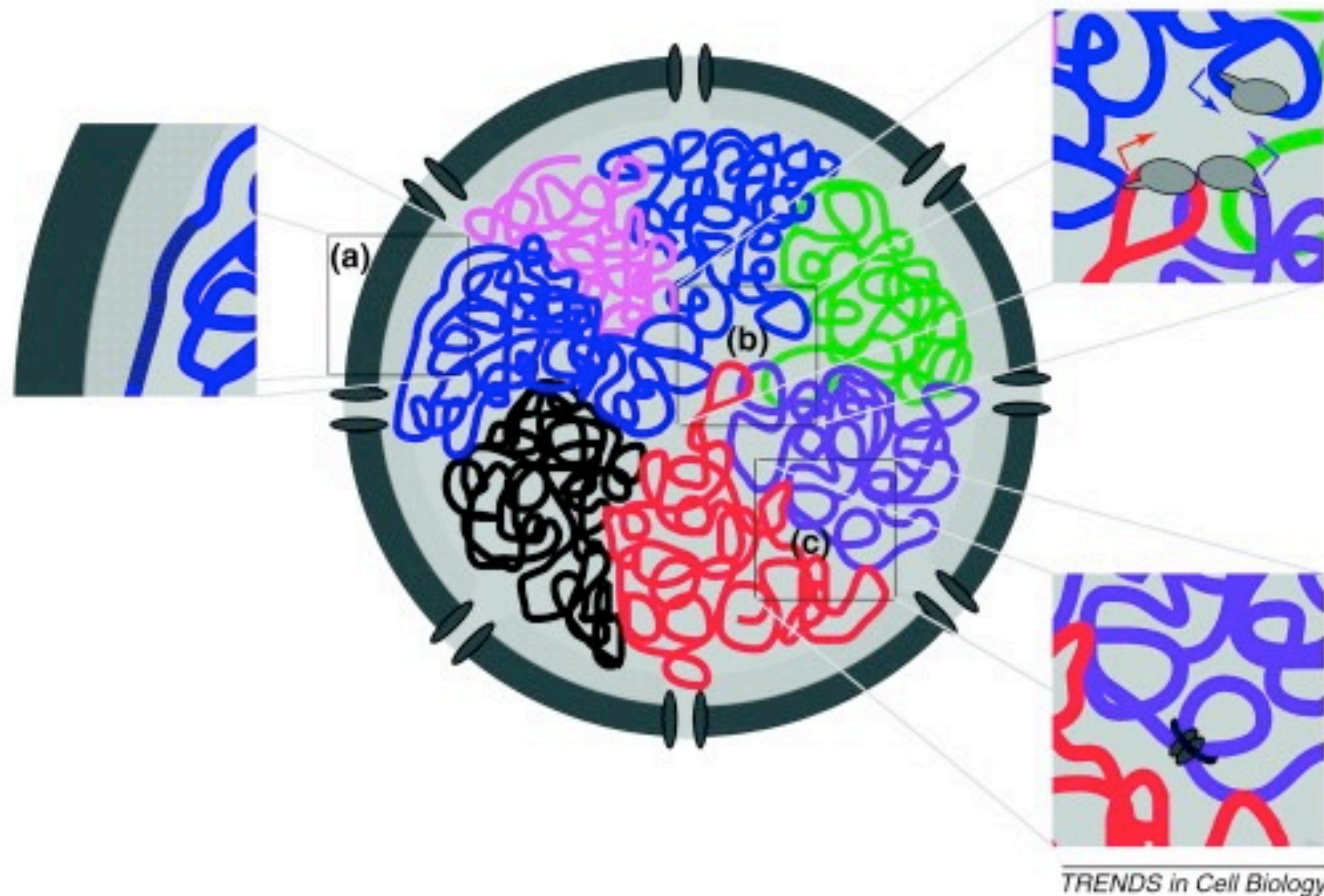


- Coordinately Controlled Genes in Eukaryotes
- Water soluble hormones need not enter the cell, instead they trigger a signal transduction pathway that leads to the activation of specific transcription activators or repressors.



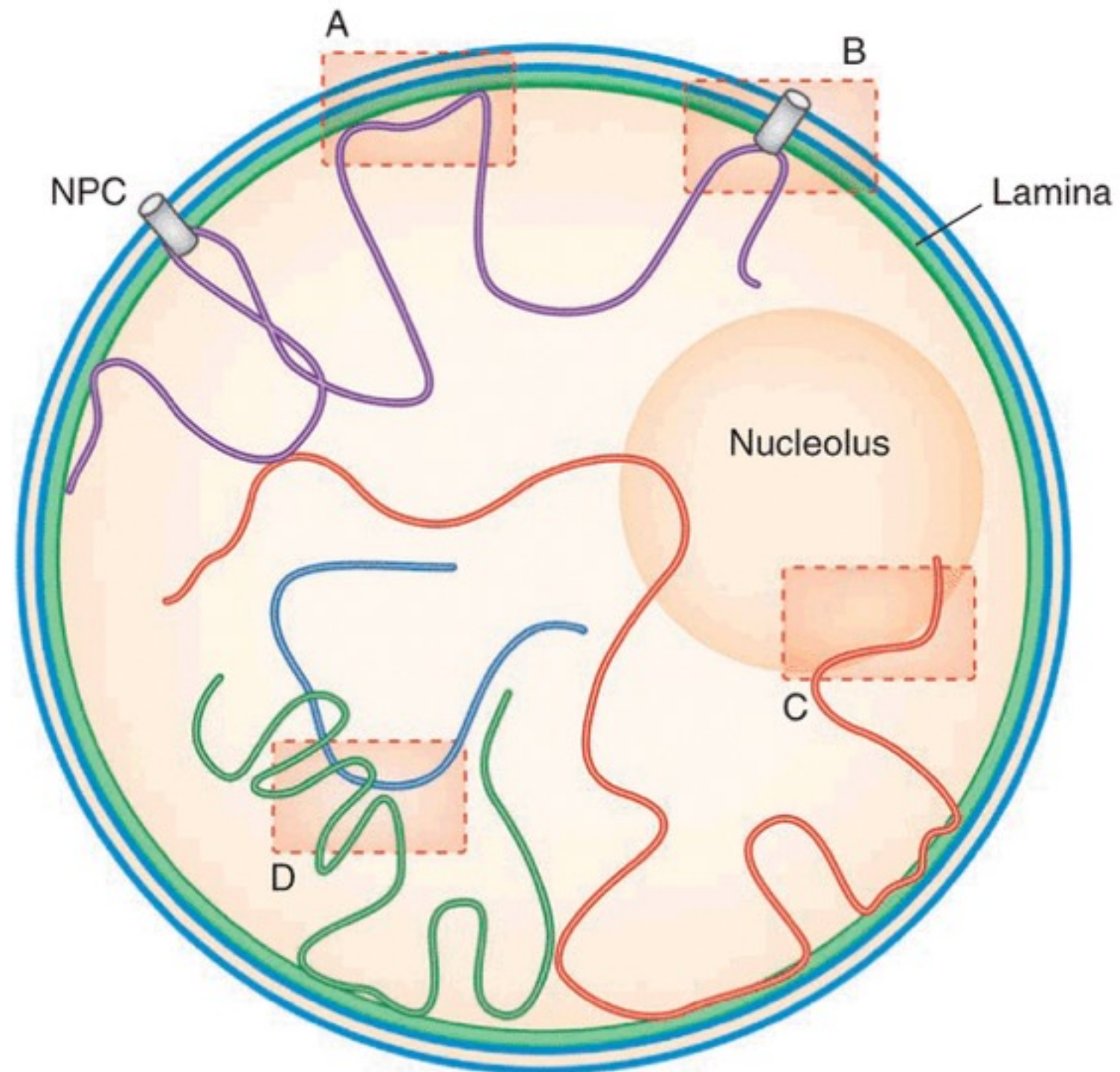


- Nuclear Architecture and Gene Expression
- The organization of chromosomes is not random, each chromosome has its own unique position, held in place by attaching to the nuclear envelope and overlapping certain other chromosomes.





- Nuclear Architecture and Gene Expression
- The areas where chromosomes overlap (D) are rich in RNA polymerases and transcription factors.
- These overlapping regions are called transcription factories.



Essential knowledge 3.B.1: Gene regulation results in differential gene expression, leading to cell specialization.

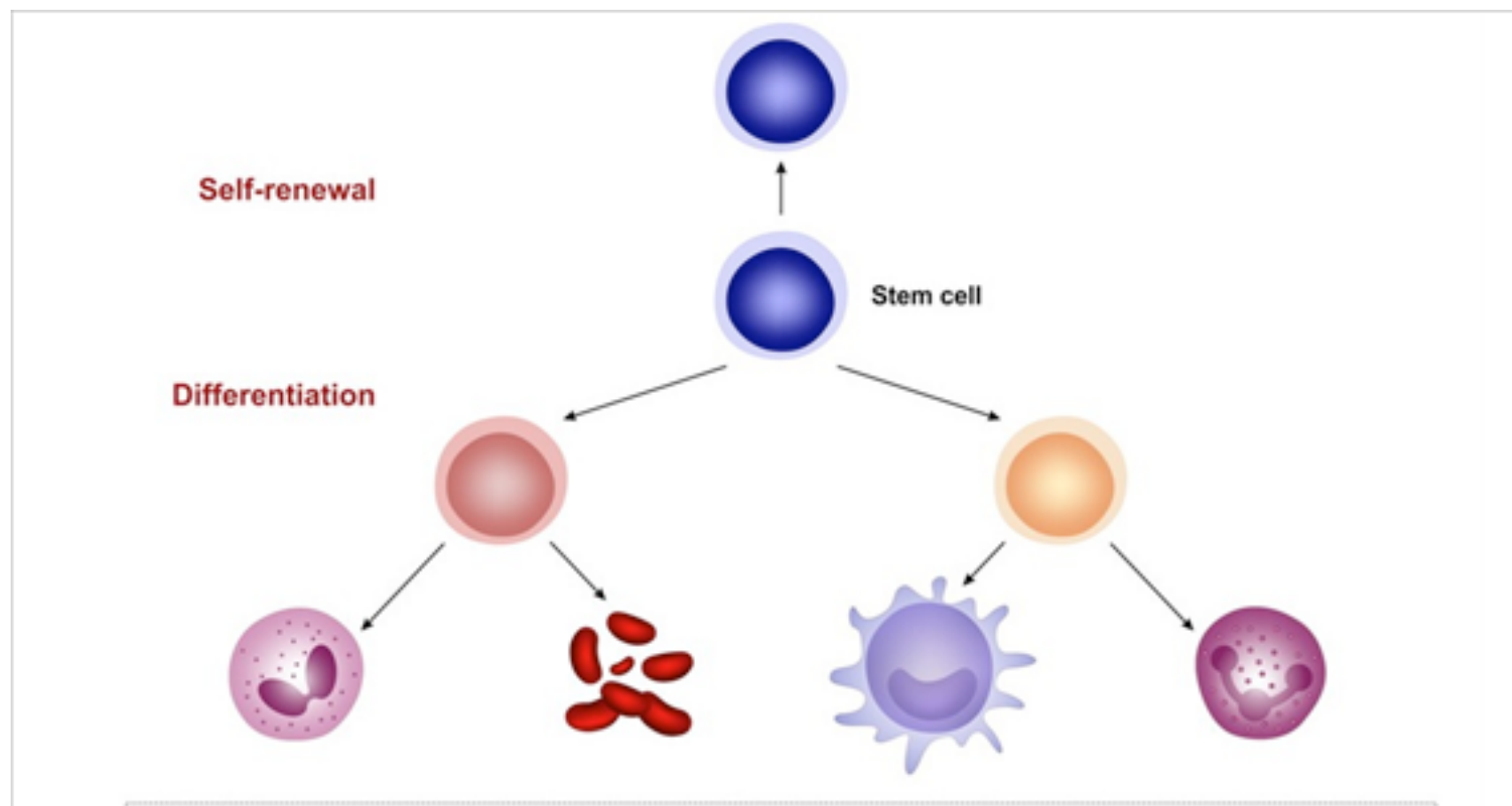
d. Gene regulation accounts for some of the phenotypic differences between organisms with similar genes.

# Differential Gene Expression

- Typical human cells expresses ~20% of its genes at any given time
  - highly differentiated cells like nerve cells even less
- Almost all cells have an identical genome
  - immune cells are an exception
- The difference between cell types are not due to different genes present but to **differential gene expression**, each cell using its own unique combination of genes.

# Differential Gene Expression

- The function of any cell depends on the appropriate set of genes being expressed.
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# Molecular Basis of Inheritance

**Main Idea:** Gene regulation and expression plays a critical role in the orchestration of development in animals.





# Embryonic Development Genes

- The transformation of a zygote into a multicellular organism is amazing and relies on three processes: cell division, cell differentiation & morphogenesis.
- **Cell division** generates the vast number of cells required to build say a human.
- **Cell differentiation** is the process where cells become specialized in structure and function.
- **Morphogenesis** organizes and arranges these specialized cells into a particular 3-dimensional arrangement that gives it creative form.

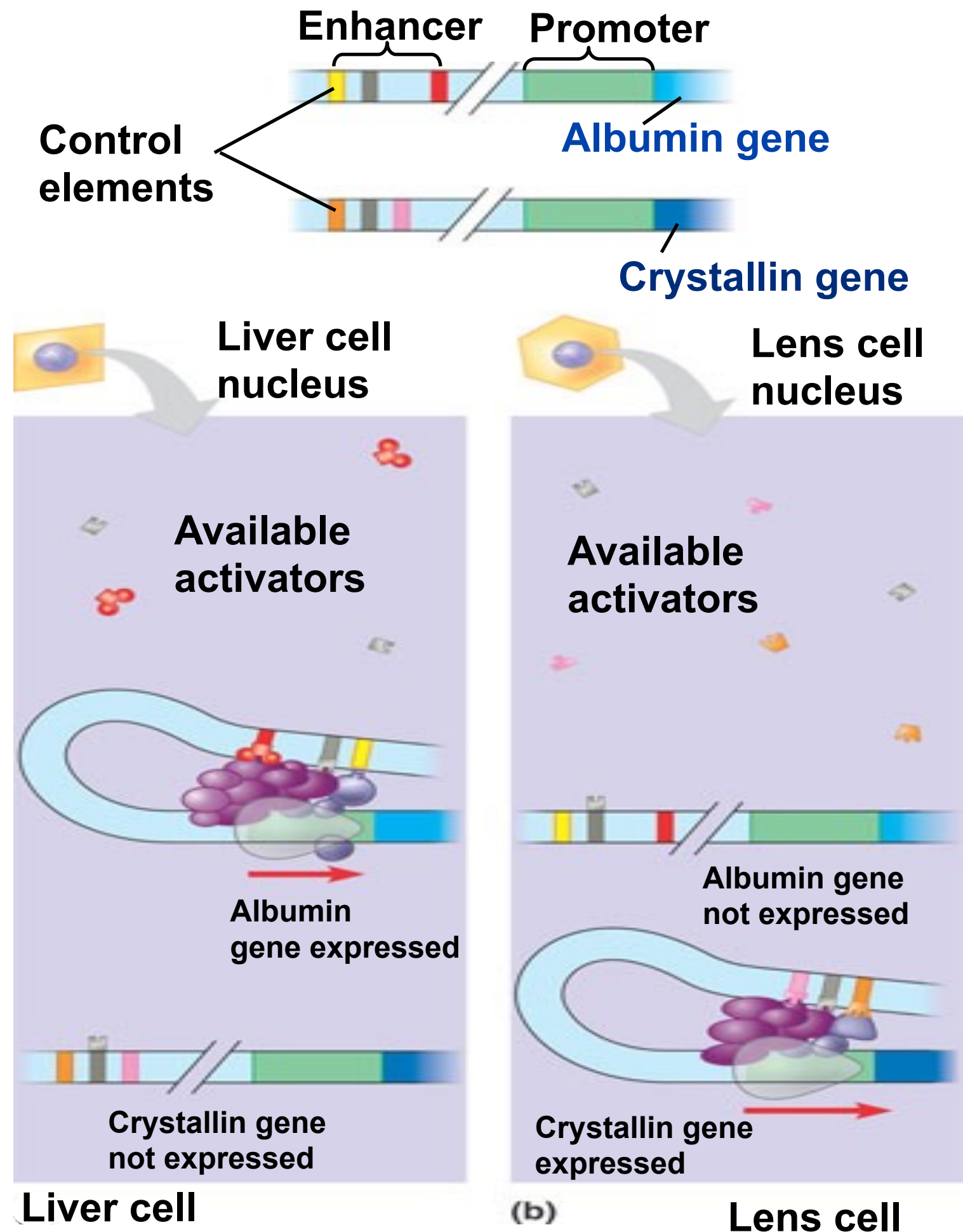
# Embryonic Development Genes

- All three processes: cell division, cell differentiation & morphogenesis have their basis in cellular behavior.
- Cellular form and behavior depend on the genes it expresses and the proteins it produces.
- Remember almost all cells in an organism have the same genome, thus differential gene expression results when cells regulate the genes differently from other cell types.

# ● Recall

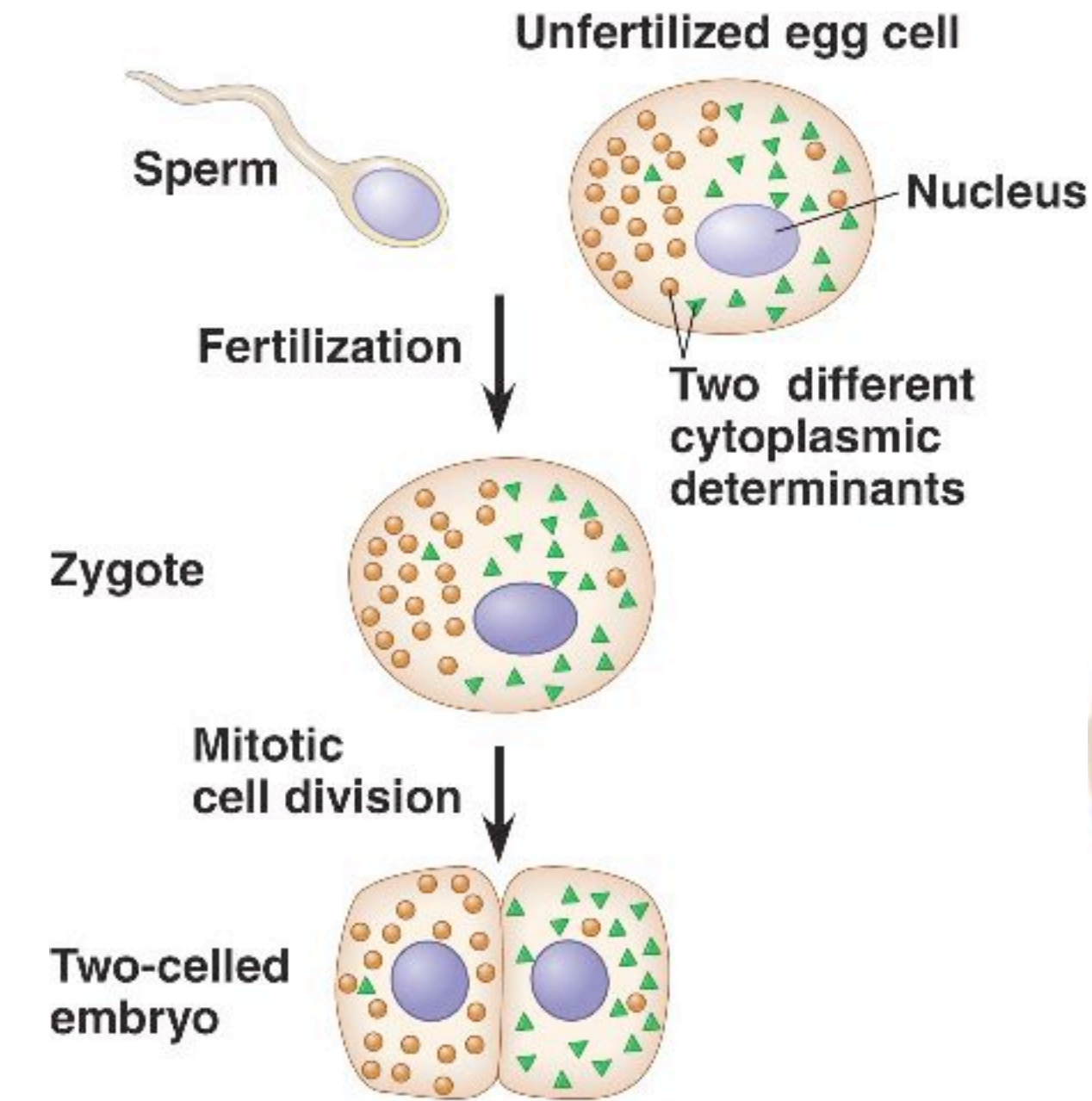
Both cells arose from the same zygote through mitosis. So...

How do different sets of activators come to be present in the two cells?



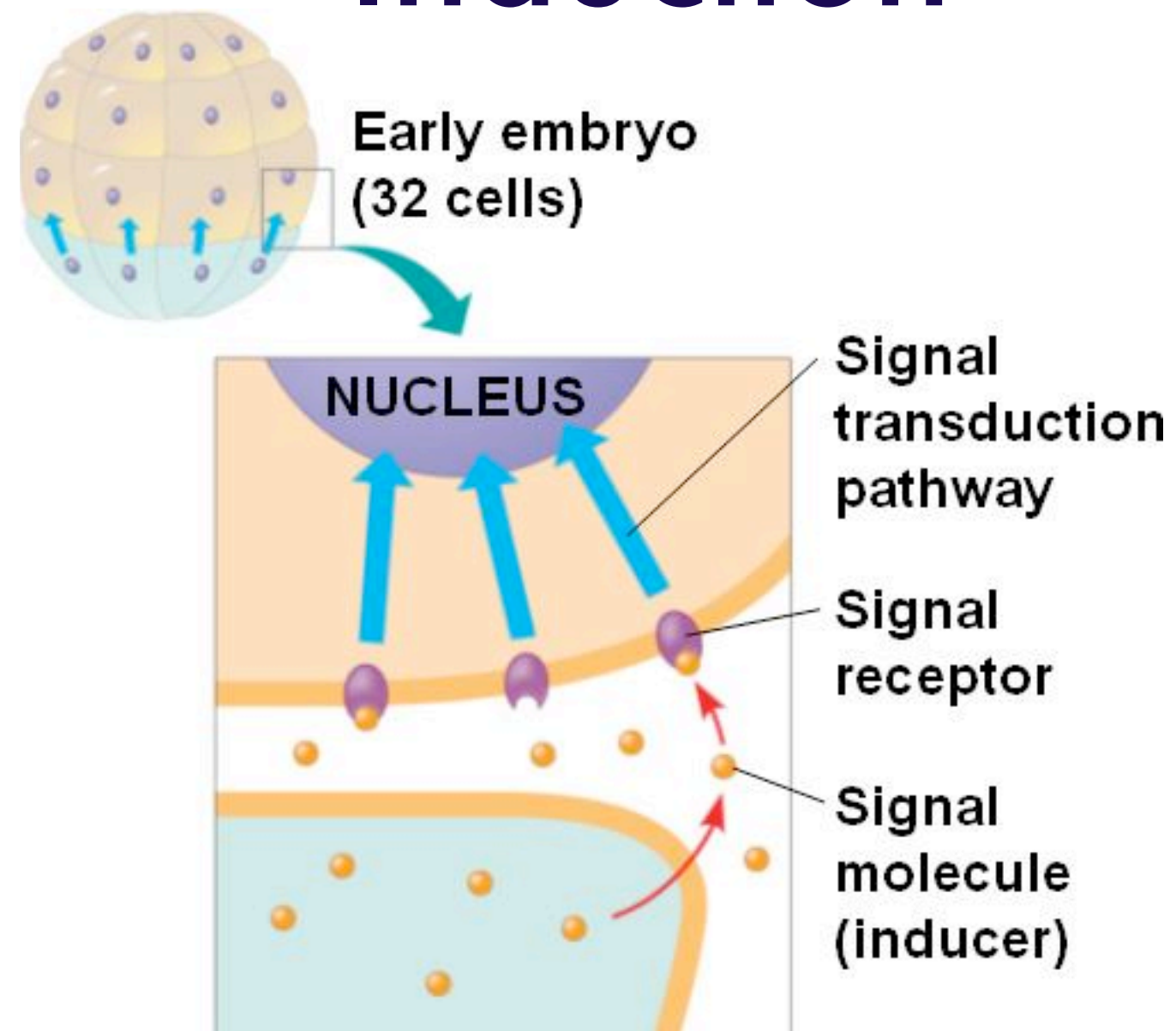
# Cytoplasmic Determinants & Inductive Signals

- Two sources of information used by early cells of the embryo tell a the cell which genes to express at any given time in development:
- 1. **Cytoplasmic determinants**- maternal substances in the egg, RNAs proteins and other substances play a profound role.
- 2. The environment around the developing cells, particularly **inductive signals** that come from other cells in the vicinity.



# Cytoplasmic Determinants

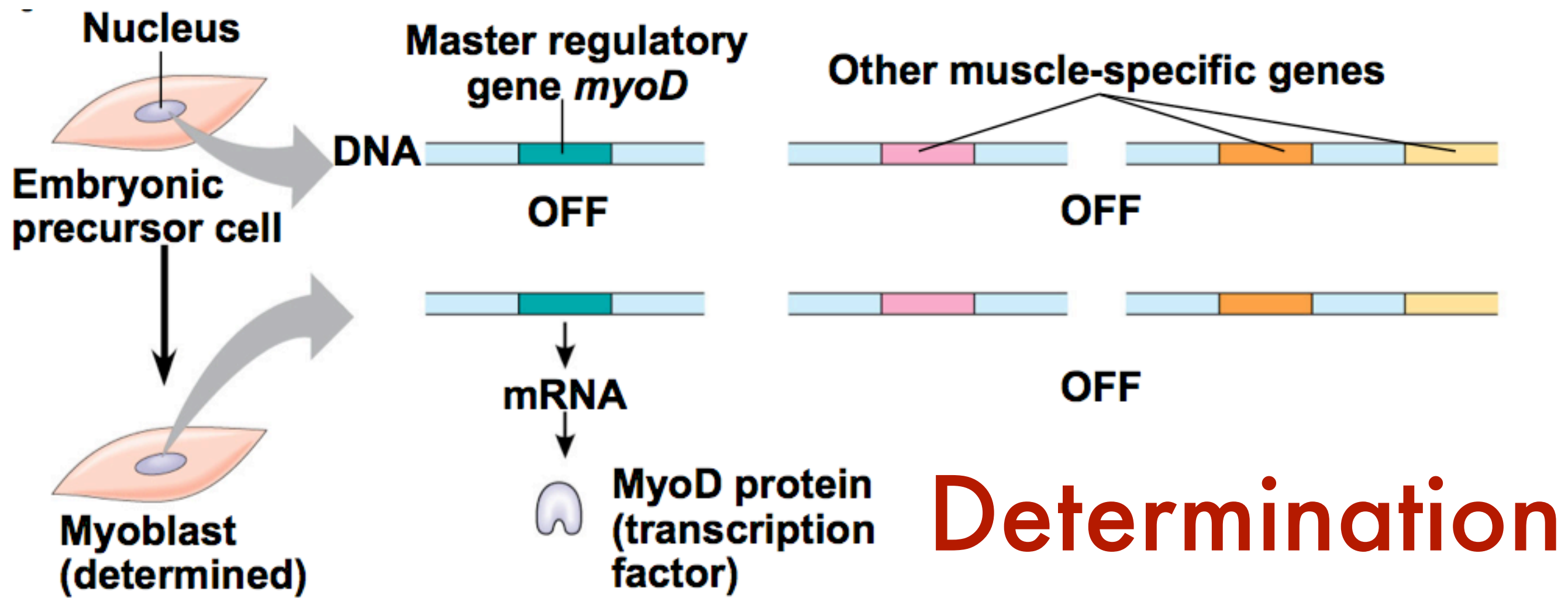
# Induction





# Sequential Regulation of Gene Expression During Differentiation

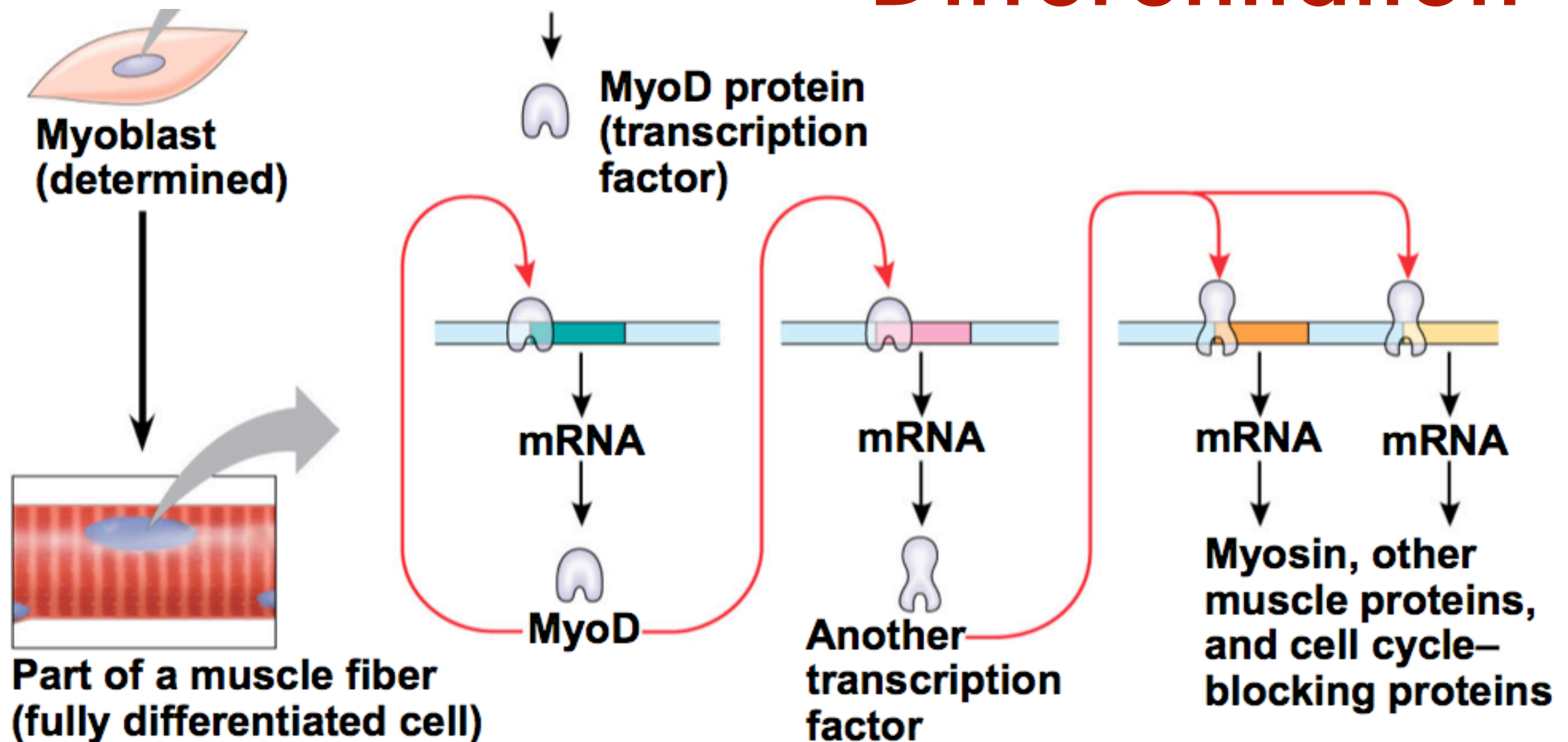
- Determination commits a cell to its final type
- Determination precedes differentiation
- Cell differentiation is marked by the production of tissue-specific proteins



- Myoblasts produce muscle-specific proteins and form skeletal muscle cells
- *MyoD* is one of several “master regulatory genes” that produce proteins that commit the cell to becoming skeletal muscle

- The MyoD protein is a transcription factor that binds to enhancers of various target genes

# Differentiation



# Learning Objectives:

LO 3.18 The student is able to describe the connection between the regulation of gene expression and observed differences between different kinds of organisms. [See SP 7.1]

LO 3.19 The student is able to describe the connection between the regulation of gene expression and observed differences between individuals in a population. [See SP 7.1]

LO 3.20 The student is able to explain how the regulation of gene expression is essential for the processes and structures that support efficient cell function. [See SP 6.2]

LO 3.21 The student can use representations to describe how gene regulation influences cell products and function.  
[See SP 1.4]