



Prescott's **MICROBIOLOGY**

ELEVENTH EDITION

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Chapter 14

Regulation of Bacterial Cellular Processes

Common Regulatory Mechanisms in Bacteria

Regulation of gene expression.

- Transcription initiation.
- Transcription elongation.
- Translation.

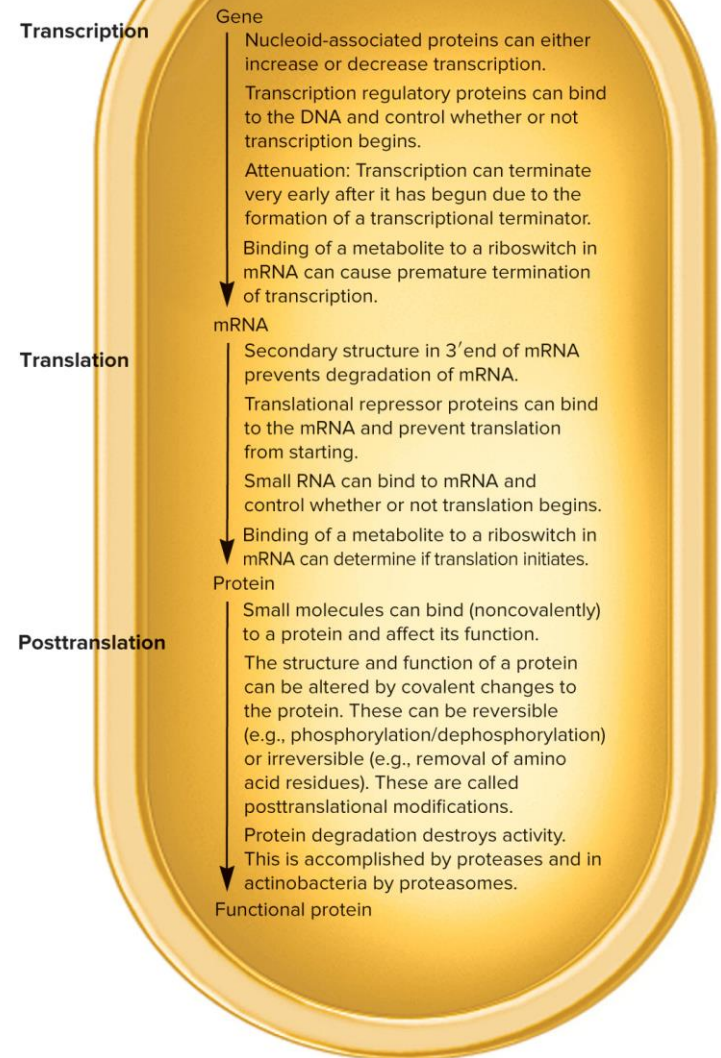
Alter activity of enzymes and proteins.

- Posttranslational.

Three domains of life differ in genome structure and regulatory mechanisms used.

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BACTERIA



Regulation of Transcription Initiation

Replacement of degraded enzymes.

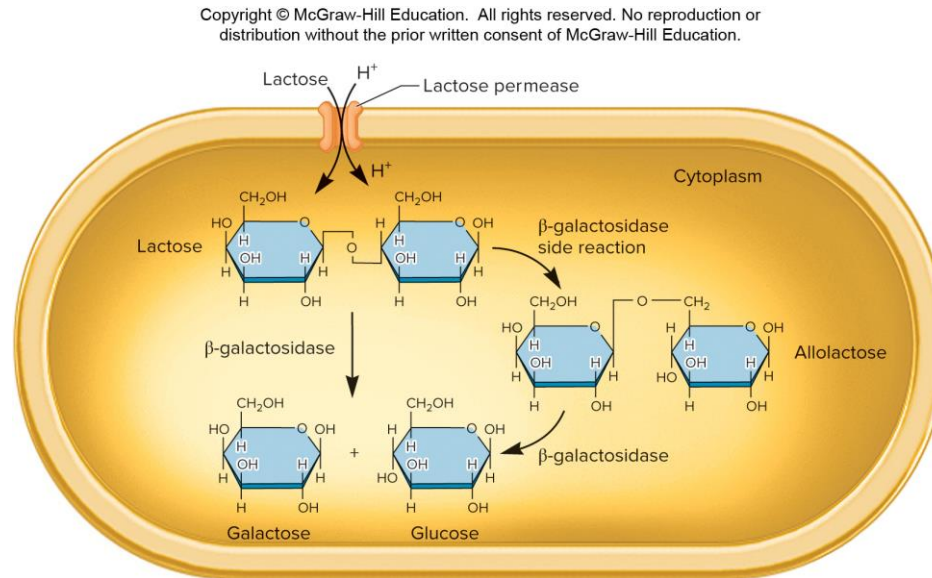
- Constitutive genes—housekeeping genes that are expressed continuously by the cell.
- Inducible genes—genes that code for inducible enzymes needed only in certain environments (such as β -Galactosidase).

Inducible Genes β -Galactosidase Enzyme

Inducible enzyme functions in a catabolic pathway.

Inducible enzymes are present only when their substrate (**inducer-effector molecule**) is available.

β -galactosidase catalyzes hydrolysis of lactose into galactose and glucose.



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Repressible Genes

Enzymes that function in **biosynthetic pathways** are products of **repressible genes**.

Generally these enzymes are always present unless the end product in the biosynthetic pathway is available.

Control of Transcription Initiation by Regulatory Proteins

Induction and repression occur **because of the activity of regulatory proteins and DNA-binding domains.**

These proteins either **inhibit transcription (negative control)** or **promote transcription (positive control).**

Negative Transcriptional Control

Binding of regulatory protein at DNA regulatory site inhibits initiation of transcription.

- mRNA expression is reduced.

Repressor proteins.

- Exist in active and inactive forms.
- Inducers/corepressors alter activity of repressor by binding.

Positive Transcriptional Control

Binding of a regulatory protein at a regulatory region on DNA promotes transcription initiation.

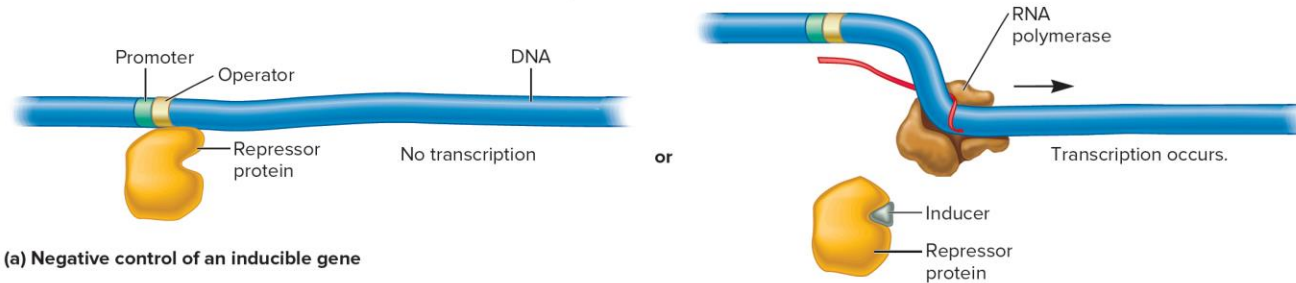
- mRNA synthesis is increased.

Activation.

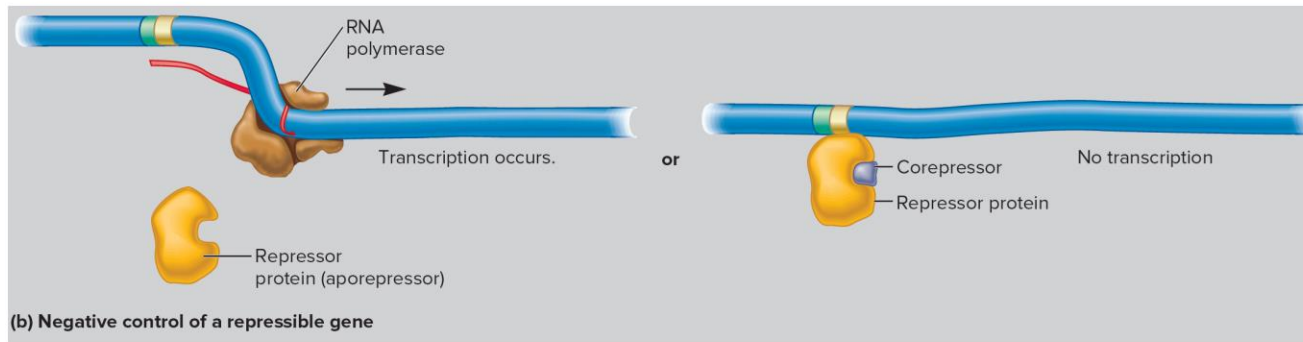
- Inactive protein is activated by inducer.
- Active protein is inactivated by inhibitor.

Examples of Transcriptional Control

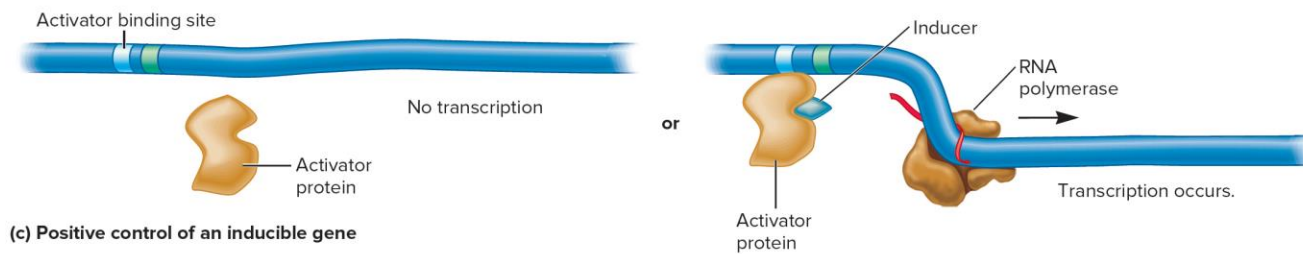
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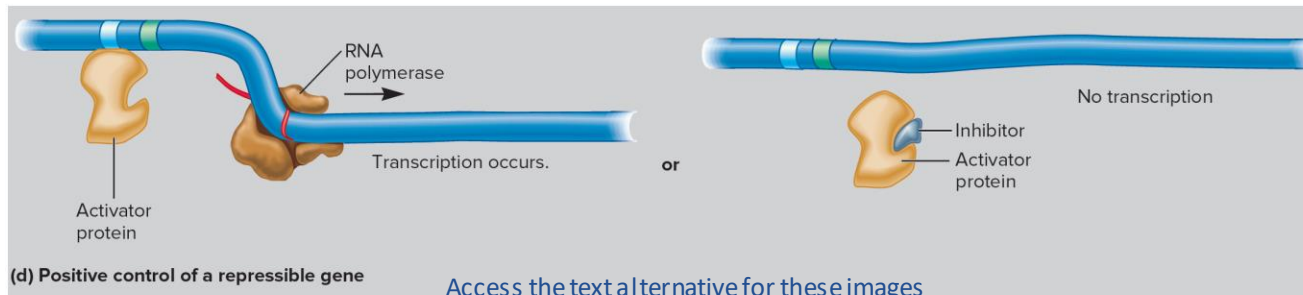
(a) Negative control of an inducible gene



(b) Negative control of a repressible gene



(c) Positive control of an inducible gene



(d) Positive control of a repressible gene

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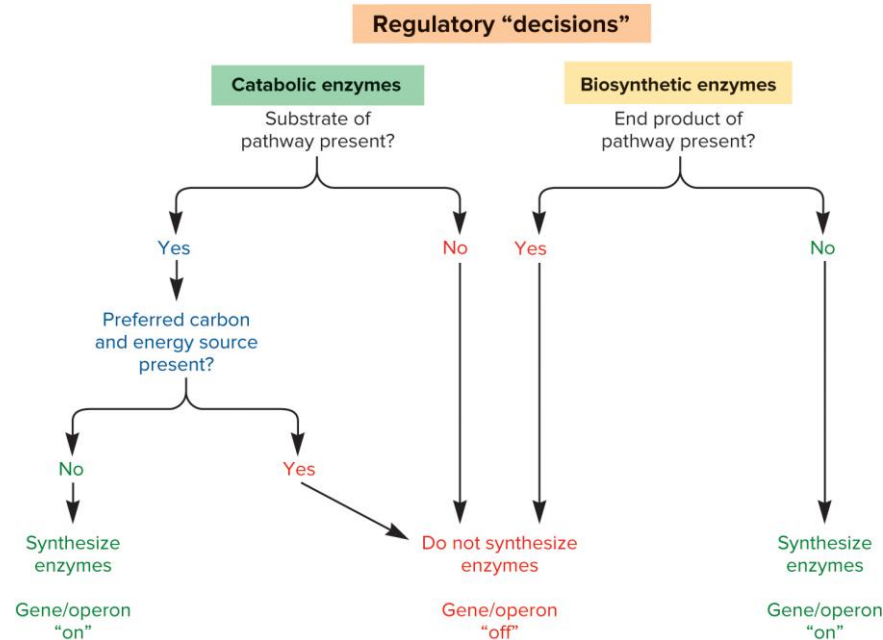
“Decision” Process in Gene Expression

Enzymes of catabolite pathway only needed (increased mRNA synthesis) when preferred substrate is available.

Enzymes not synthesized when substrate absent.

Efficient use of energy and materials.

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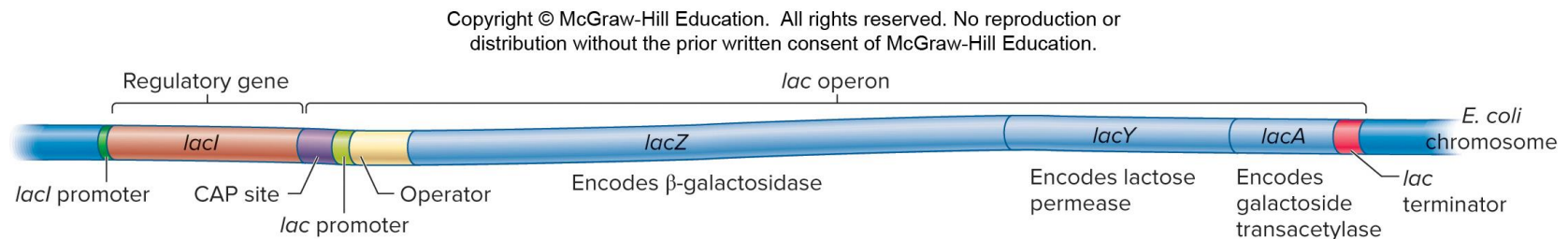
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Negative Control of Lactose (*lac*) Operon

Inducible genes

- Three structural genes coding for lactose uptake and metabolism
- *lac* repressor (*lacI*) binds operator, inhibits transcription

Enzymes normally not produced unless lactose present



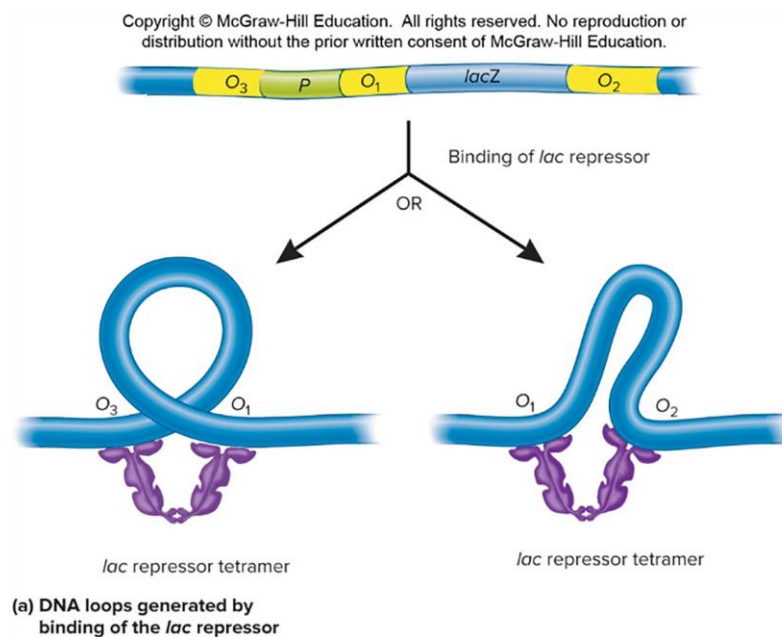
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lac Repressor

Tetramers of repressor form and bind to three operator sites (O_1 , O_2 , O_3).

Bends DNA, prevents RNA polymerase from accessing promoter

Presence of allolactose binds repressor—no longer binds operator.

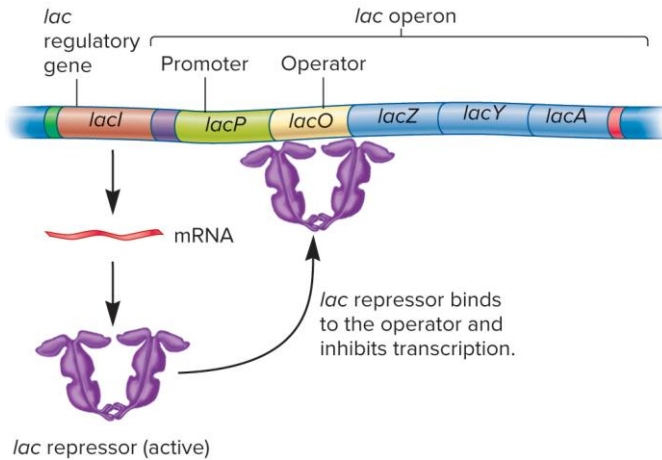


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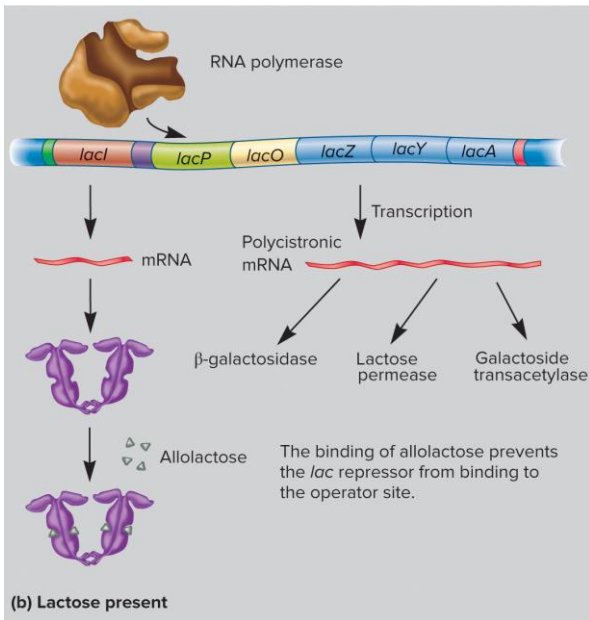
(b) *lac* repressor bound to O_1 and O_3 (red)

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(a) No lactose available

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(b) Lactose present

Regulation of *lac* Operon by *lac* Repressor

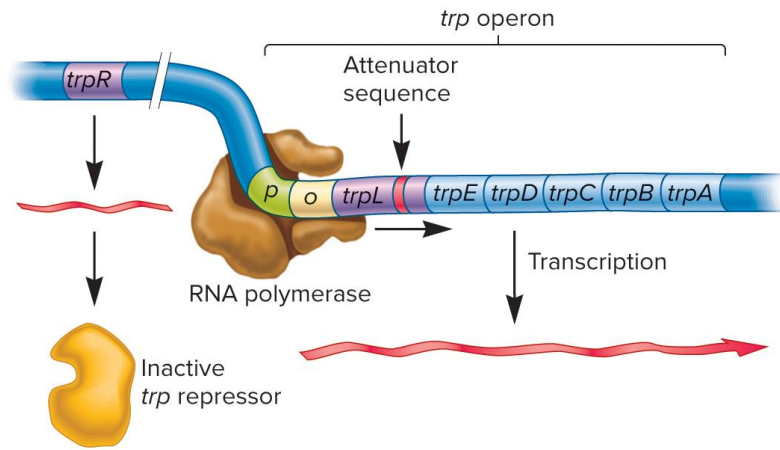
Regulated by catabolite activator protein (CAP).

- Regulates in response to presence or absence of glucose.
- Allows for preferential use of glucose.

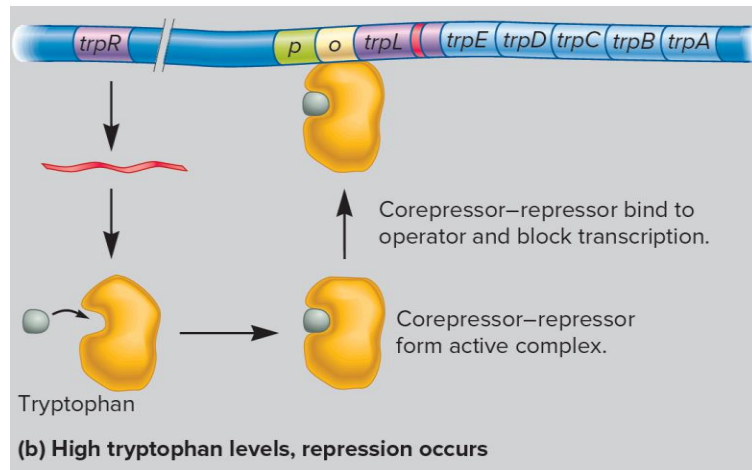
[\(268\) The Lac Operon Induction of Genes HD Animation - YouTube](#)

[\(268\) Lac Operon Regulation - Catabolite Repression: Role of cAMP, CAP & Glucose - YouTube](#)

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(a) Low tryptophan levels, transcription of the entire *trp* operon occurs



(b) High tryptophan levels, repression occurs

The Tryptophan (*trp*) Operon

Consists of 5 structural genes which code for enzymes needed to synthesize tryptophan.

Negative transcriptional control of repressible genes by *trp* repressor.

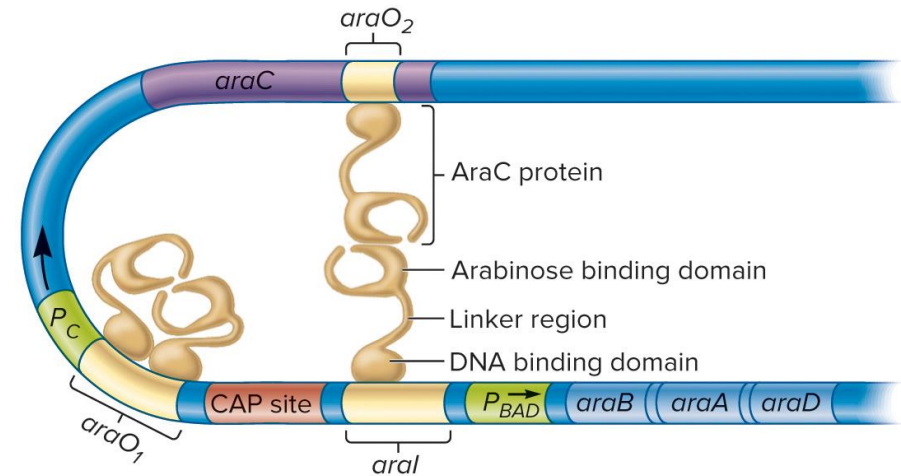
Operon only functions in the absence of tryptophan.

The Arabinose (*ara*) Operon

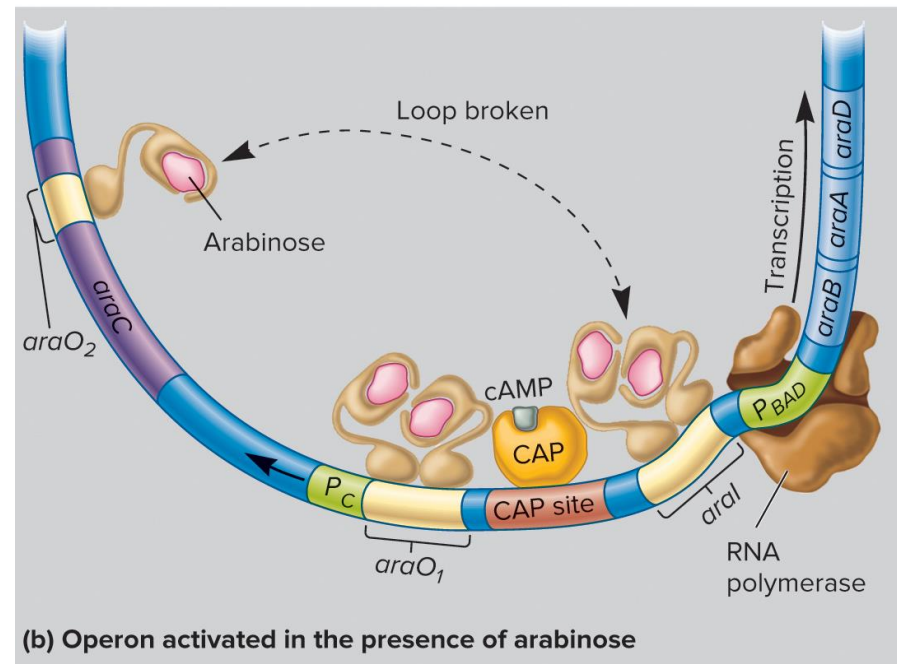
Transcriptional control by a protein (AraC) that acts both positively and negatively

- Activity depends on environmental conditions
- Inactive when arabinose present
- Active when arabinose absent

[\(268\) The Tryptophan Repressor HD Animation - YouTube](#)



(a) Operon inhibited in the absence of arabinose



(b) Operon activated in the presence of arabinose

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Global Regulatory Systems

Regulatory systems that affect many genes, operons, and pathways simultaneously.

Important for bacteria since they must respond rapidly to wide variety of changing conditions.

Regulon—genes or operons controlled by a common regulatory protein.

Mechanisms Used for Global Regulation

Global regulatory systems often use many types of regulation such as:

- Two-component signal transduction systems.
- Phosphorelay systems.
- Alternate sigma factors.
- Second messengers.

Two-Component Signal Transduction and Phosphorelays

Many genes and operons are turned on or off in response to environmental conditions.

- The regulatory proteins involved are part of a two-component signal system which links external events to regulation of gene expression.

Two-Component Signal Transduction Systems

Found in all three domains of life.

Two proteins govern pathway:

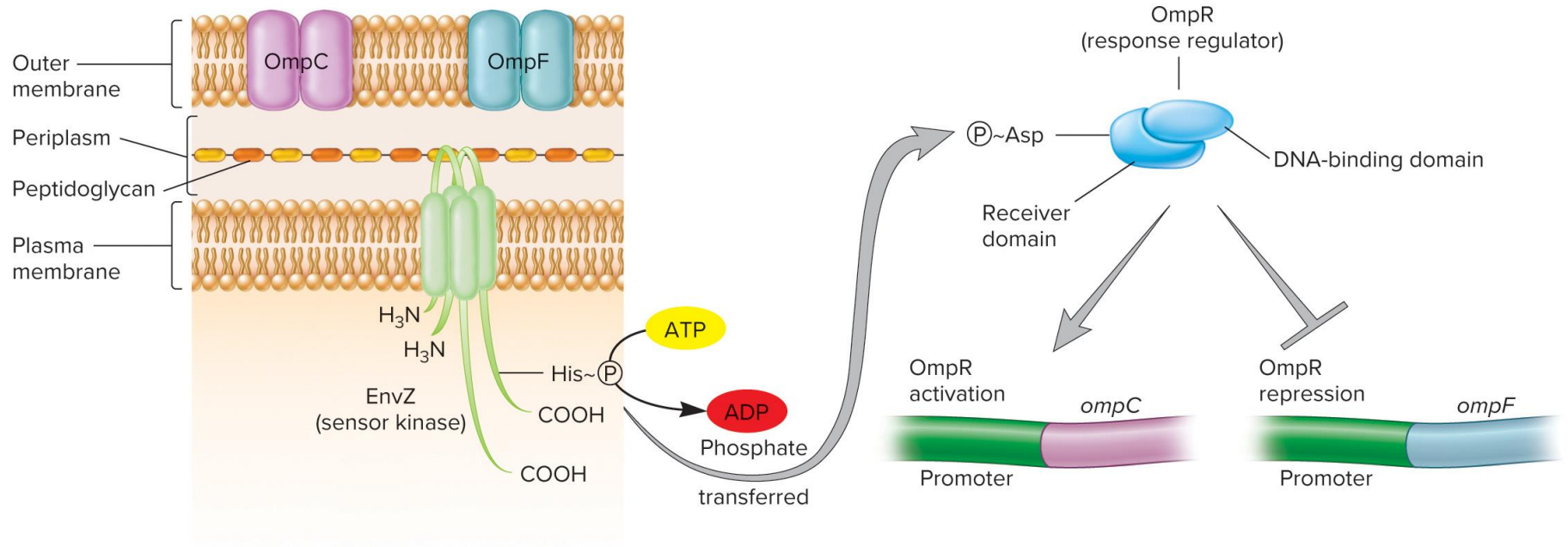
- **Sensor kinase**—extracellular receptor for metabolite; intracellular communication pathway.
- **Response regulator**—activated by sensor kinase .

Some response regulators form homodimers that bind to DNA:

- Activator—enhances transcription needed.
- Repressor—inhibits transcription unless needed.

Regulation of Porin Proteins by a Two-Component Signal Transduction System

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Phosphorelay System of Porin Proteins

Env Z (sensor kinase).

- Autophosphorylates in high osmolarity.

OmpR (response regulator).

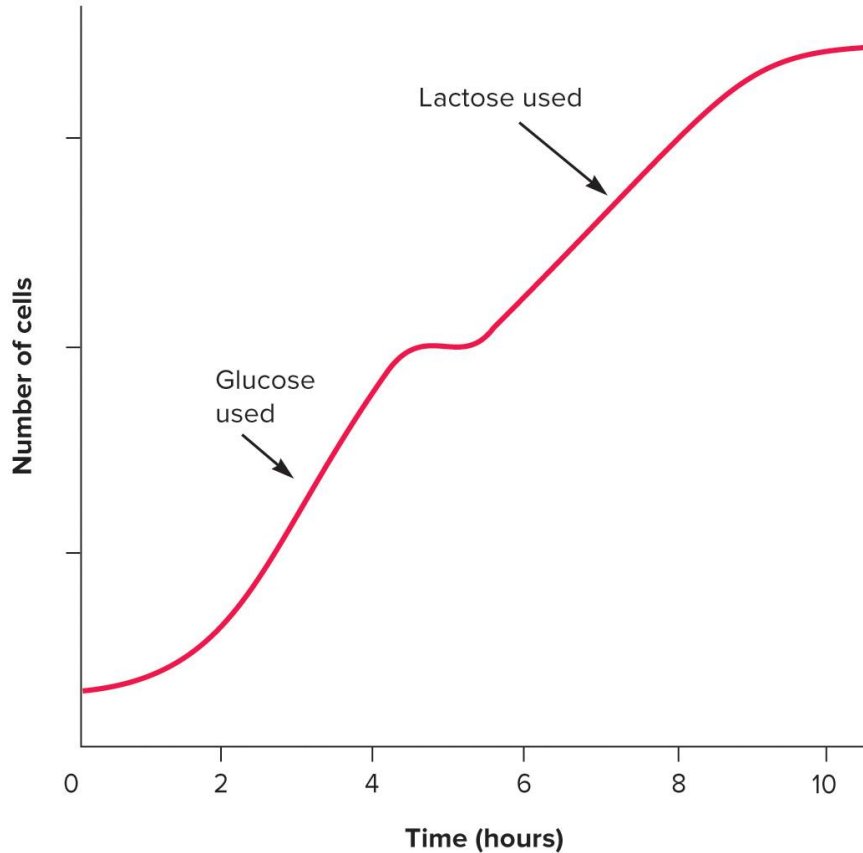
- Phosphorylated and regulates transcription.

Once OmpR is phosphorylated, it regulates transcription so that *ompF* is repressed and *ompC* is activated.

- OmpC is smaller porin protein—lower levels of diffusion.
- Omp F is larger porin protein—allows more diffusion of solutes.

Catabolite Repression

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Regulation of transcription by both repressors and activators.
Diauxic growth.

- A biphasic growth pattern—preferential use of one carbon source over another when both are available in environment
- Lag occurs—after preferred substrate is exhausted, growth resumes using the second carbon source.

Catabolite repression plays a role in this pattern of growth.

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Quorum Sensing

Cell-to-cell communication mediated by small signaling molecules such as N-acyl-homoserine lactone (AHL).

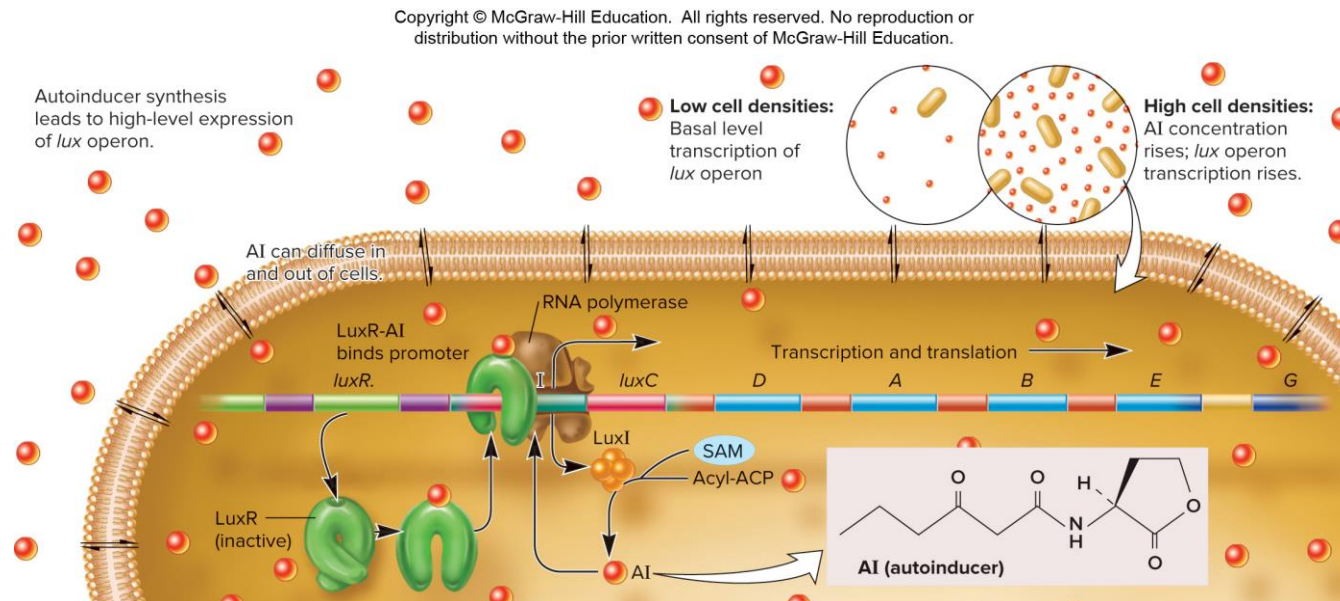
Couples cell density and intercellular communication to transcription regulation.

Plays an **essential role in the regulation of genes whose products are needed for the establishment of virulence, symbiosis, biofilm production, and morphological differentiation in a wide range of bacteria.**

Quorum Sensing in *V. fischeri*

High concentrations of AHL produced by increased density of cells diffuse back into the cell, bind to the transcriptional regulator LuxR and activate transcription.

LuxR stimulates transcription of the genes for AHL synthase (*luxI*) and proteins needed for light production.



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Response to Autoinducers by *V. harveyi*

Responds to three autoinducers.

- Maximizes expression of bioluminescence.

Low cell density.

- Low autoinducers present.
- LuxR not made, no bioluminescence.

High cell density.

- Any combination of inducers.
- LuxR made, bioluminescence occurs.

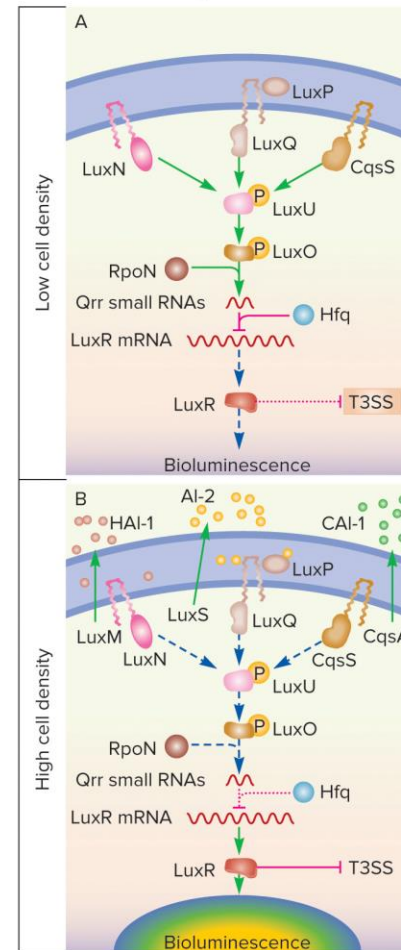
Reaction occurs, having a positive effect on the following step in the quorum-sensing response.

Reaction occurs, having a negative effect.

Positive-acting reaction does not occur.

Negative-acting reaction does not occur.

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At low cell densities, none of the autoinducers is present in sufficient quantities to inhibit the kinase activity of their respective sensor kinases. LuxU is phosphorylated and transfers the phosphate to LuxO. LuxO and the sigma factor RpoN activate production of Qrr small RNAs, which with the aid of Hfq block translation of LuxR mRNA. Because LuxR is not made, the T3SS apparatus is made, and cells do not bioluminesce.

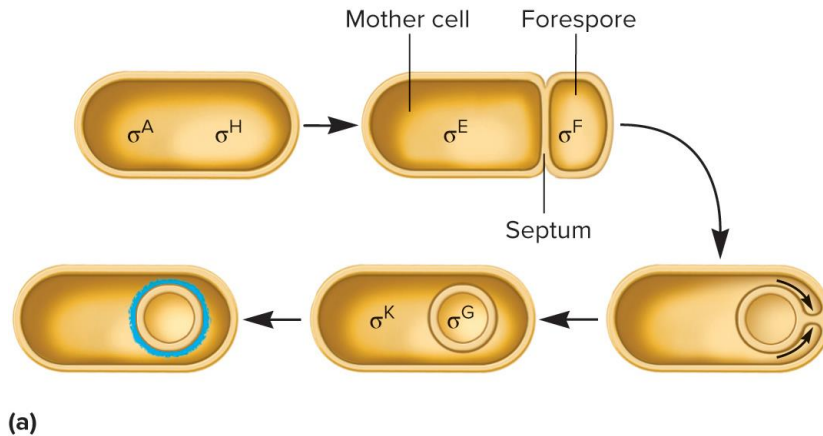
At high cell densities, any combination of autoinducers will prevent phosphorylation of LuxU and LuxO. Qrr small RNAs will not be made and LuxR mRNA will be translated. The LuxR protein will prevent synthesis of the T3SS apparatus but will promote bioluminescence.

Sporulation in *Bacillus subtilis*

Another example of a global regulatory system in which phosphorelay, posttranslational modification of proteins, transcription initiation regulatory proteins and alternative sigma factors play a role.

Starvation signal induces production of alternative sigma factors.

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