Control of Gene Expression

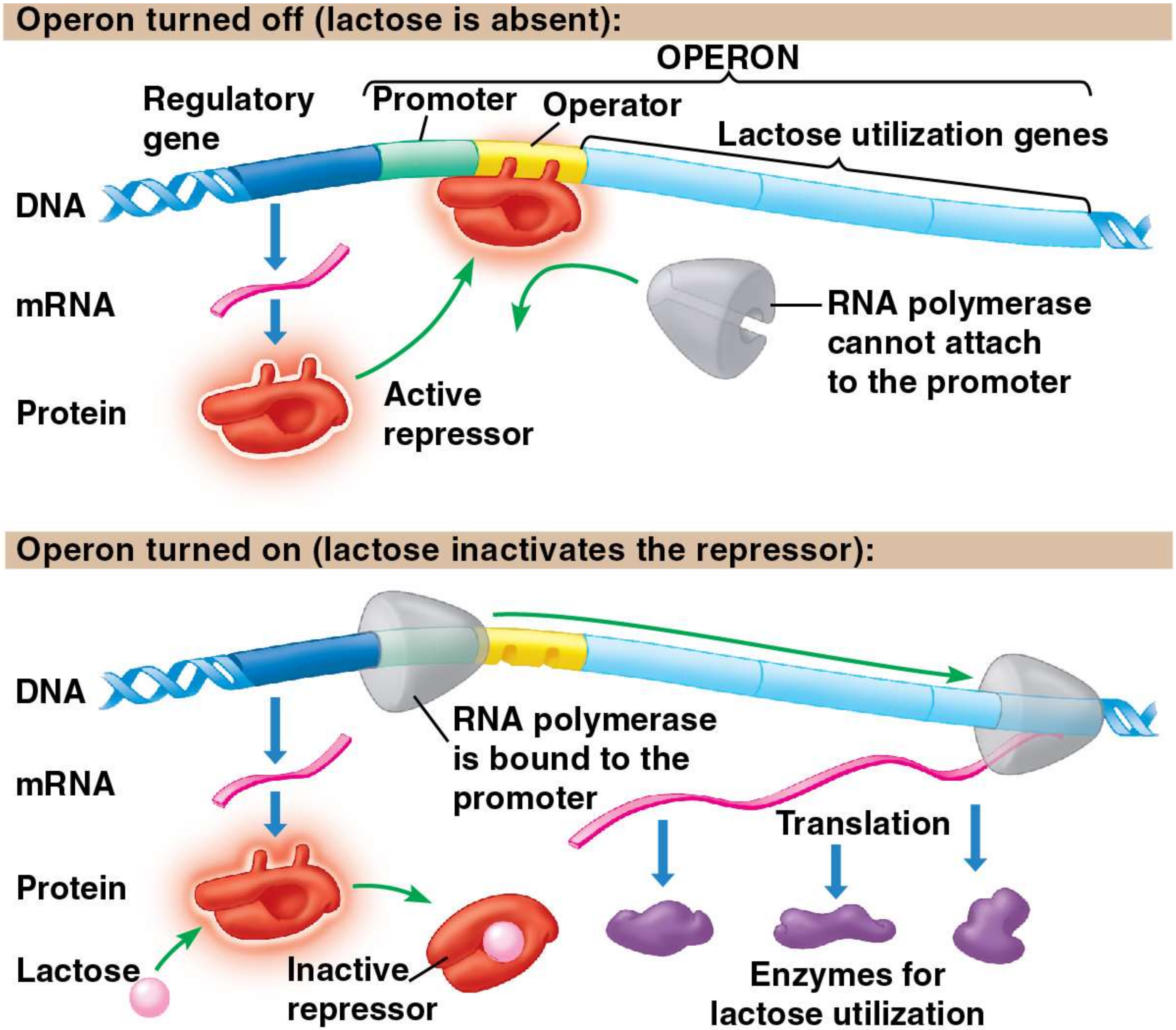
11.1 Proteins Interacting with DNA Turn Prokaryotic Genes on or off in Response to Environmental Changes (1 of 3)

- The overall process by which genetic information flows from genes to proteins—that is, from genotype to phenotype—is **gene expression**.
- **Gene regulation**, the turning on and off of genes, can help organisms respond to environmental changes.

11.1 Proteins Interacting with DNA Turn Prokaryotic Genes on or off in Response to Environmental Changes (2 of 3)

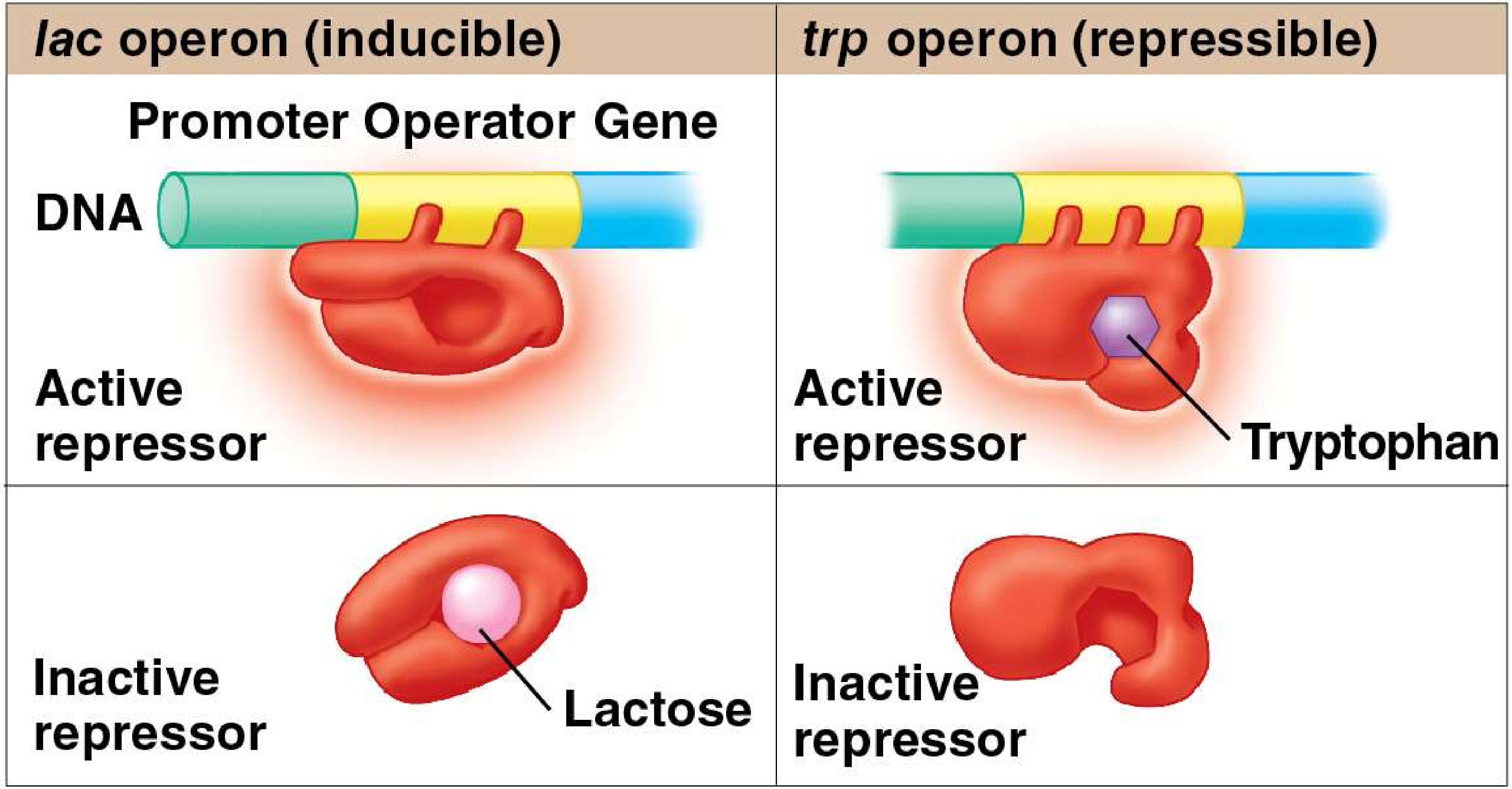
- In prokaryotes, genes for related enzymes are often controlled together in units called **operons**.
- Regulatory proteins bind to control sequences in the DNA.

Figure 11.1b



Operon turned off (lactose is absent):
OPERON
Regulatory gene
Promoter
Operator
Lactose utilization genes
DNA
mRNA
Protein
Active repressor
RNA polymerase cannot attach to the promoter
Operon turned on (lactose inactivates the repressor):
DNA
mRNA
Protein
Lactose
RNA polymerase is bound to the promoter
Translation
Inactive repressor
Enzymes for lactose utilization

Figure 11.1c


lac operon (inducible)
trp operon (repressible)
Promoter Operator Gene
DNA
Active repressor
Active repressor
Tryptophan
Inactive repressor
Lactose
Inactive repressor

11.1 Proteins Interacting with DNA Turn Prokaryotic Genes on or off in Response to Environmental Changes (3 of 3)

Checkpoint question A certain mutation in *E. coli* impairs the ability of the *lac* repressor to bind to the lac operator. How would this affect the cell?

The cell would produce the enzymes for lactose metabolism continuously, even when lactose is not present, thereby wasting energy.

11.2 Chromosome Structure and Chemical Modifications Can Affect Gene Expression (1 of 3)

- As a zygote develops into a multicellular organism, individual cells must undergo **differentiation**, becoming specialized in structure and function.
  - Each cell type must maintain a specific regimen of gene expression in which some genes are expressed and others are not.
  - The differences between cell types, therefore, are not due to different genes being present but instead due to selective gene expression.

11.2 Chromosome Structure and Chemical Modifications Can Affect Gene Expression (2 of 3)

- A chromosome contains DNA wound around clusters of small proteins called **histones**, forming a string of bead-like **nucleosomes**.
- DNA packing tends to block gene expression by preventing access of transcription proteins to DNA.
  - One example of DNA packing is **X chromosome inactivation** in the cells of female mammals.
  - Chemical modification of DNA bases or histone proteins can result in **epigenetic inheritance**.

Figure 11.2b_1

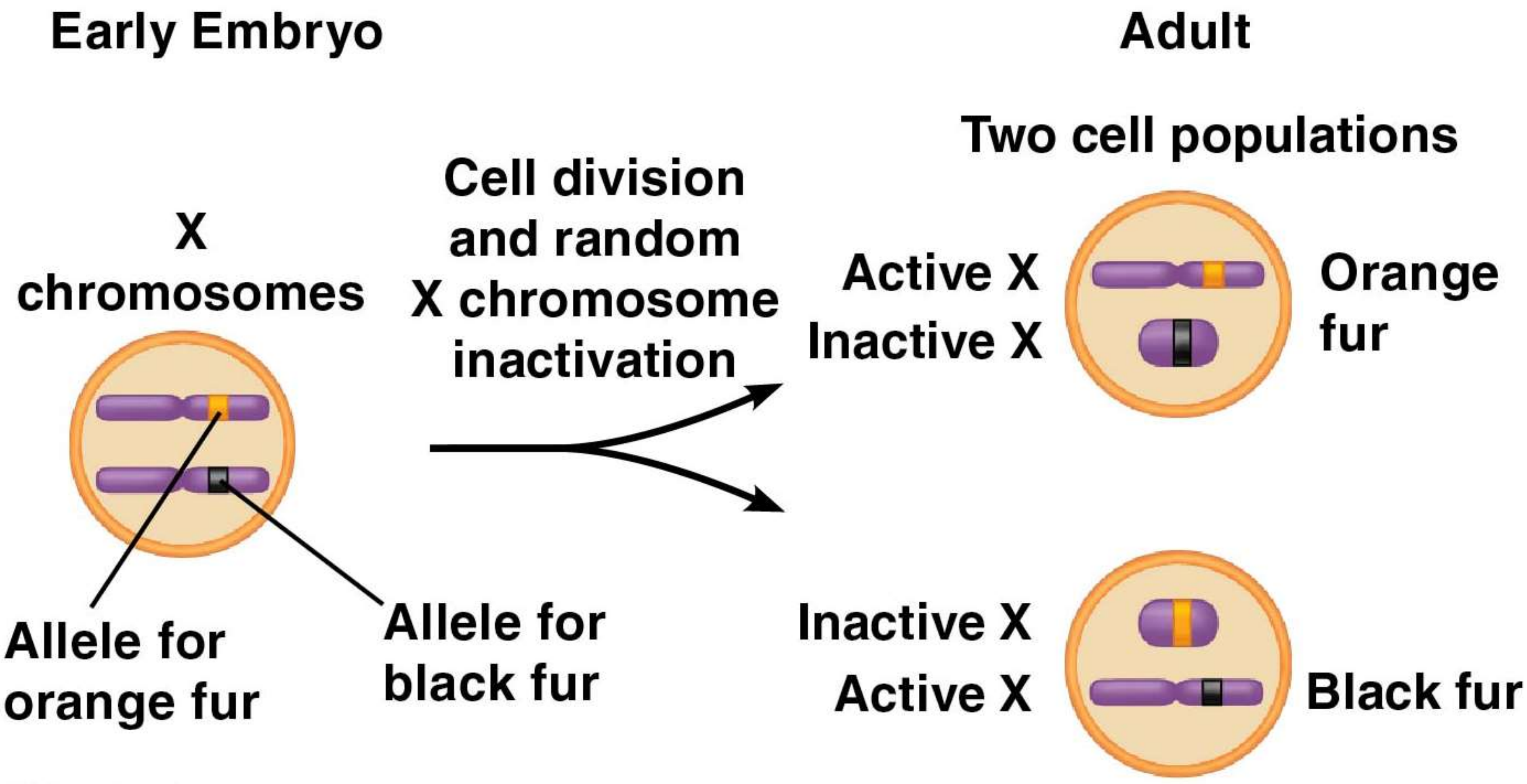
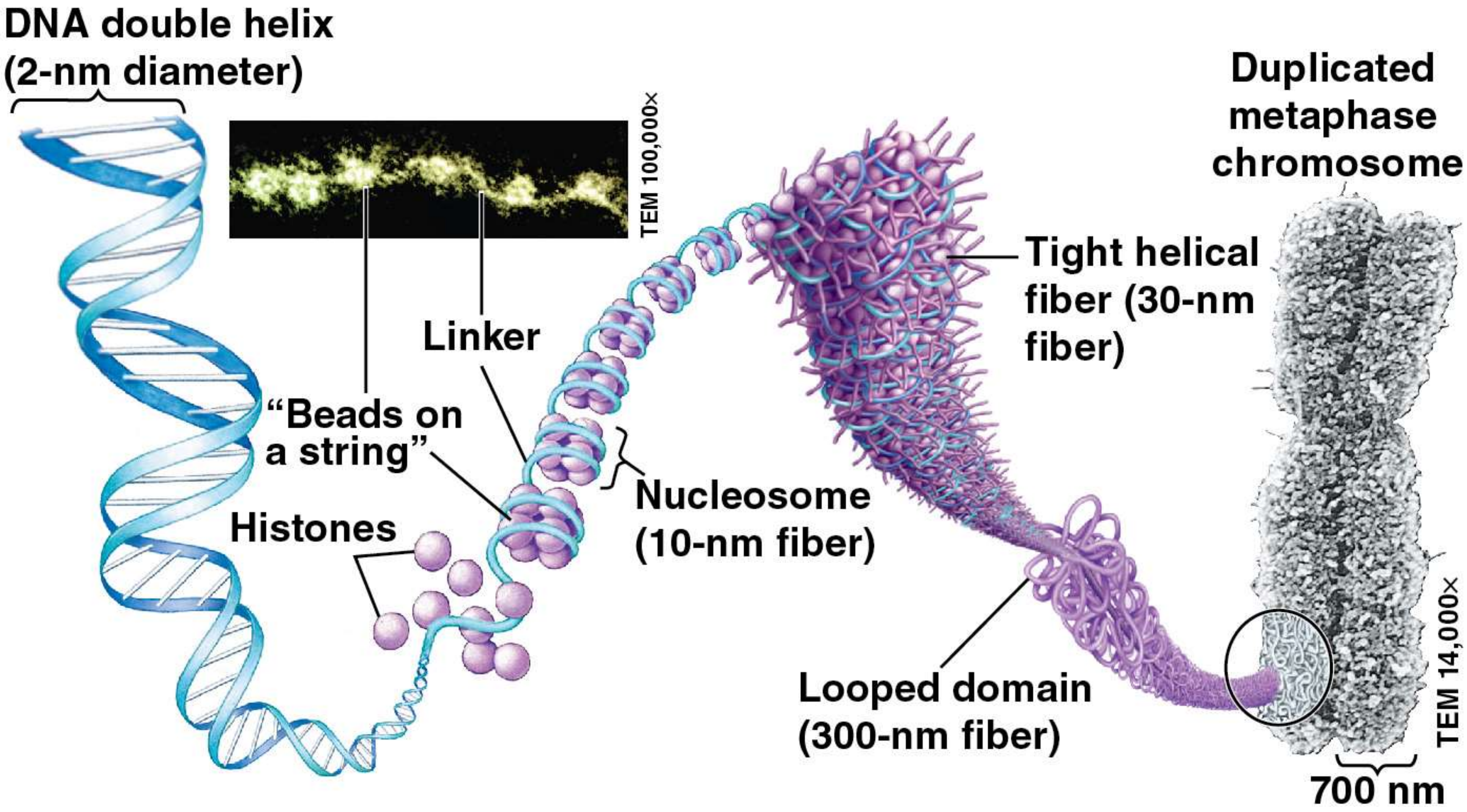


Figure 11.2a



DNA double helix
(2-nm diameter)
TEM 100,000×
Linker
"Beads on
a string"
Histones
Nucleosome
(10-nm fiber)
Tight helical
fiber (30-nm
fiber)
Duplicated
metaphase
chromosome
Looped domain
(300-nm fiber)
TEM 14,000×
700 nm

11.2 Chromosome Structure and Chemical Modifications Can Affect Gene Expression (3 of 3)

Checkpoint question In your body, a nerve cell has a very different structure and performs very different functions than a skin cell. Because the two cell types have the same genes, how can the cells be so different?

Each cell type must be expressing certain genes that are present in, but not expressed in, the other cell type.

11.3 Complex Assemblies of Proteins Control Eukaryotic Transcription (1 of 2)

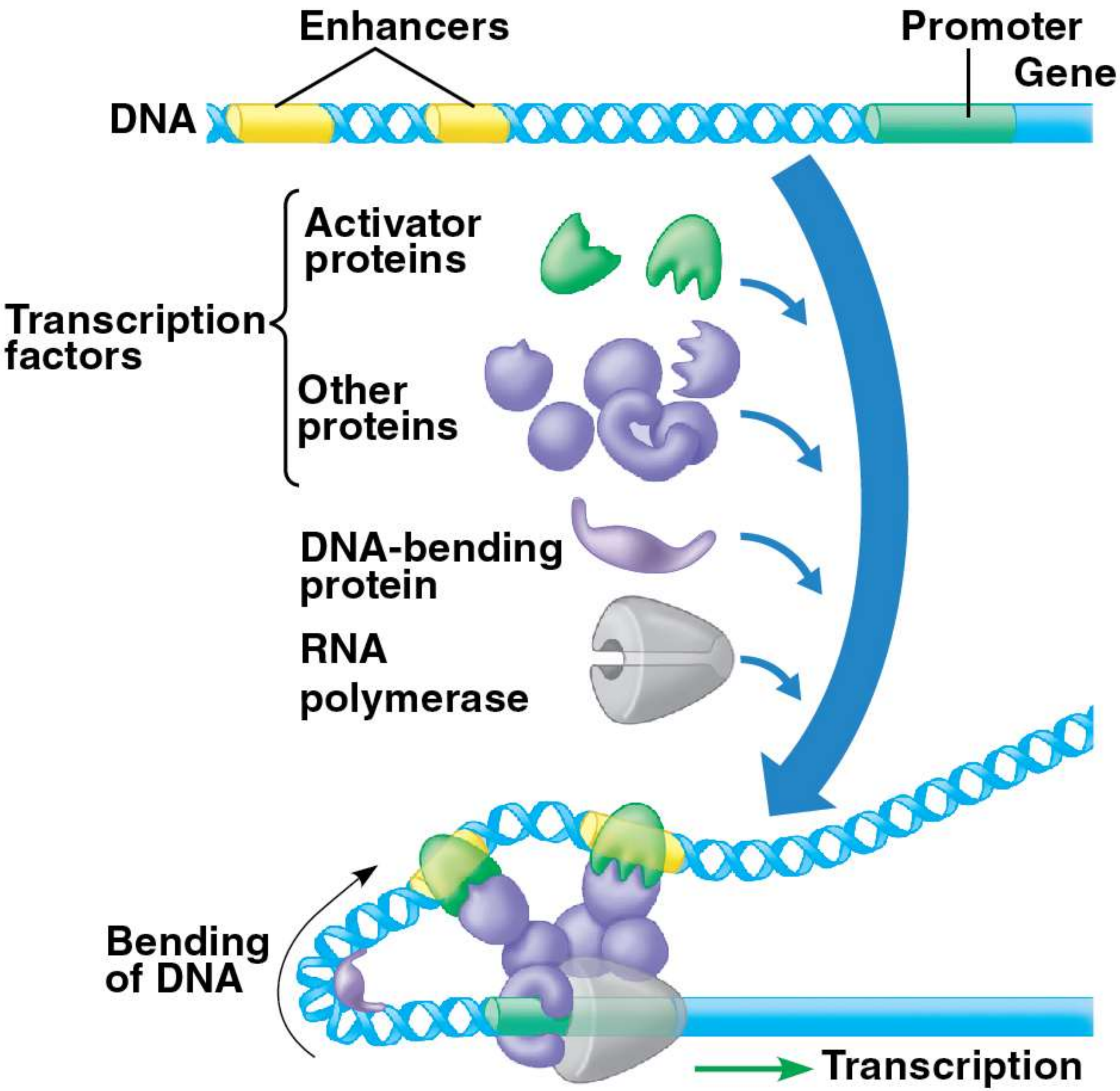
- A variety of regulatory proteins interact with DNA and with each other to turn the transcription of eukaryotic genes on or off.
- **Transcription factors** are proteins that promote the binding of RNA polymerase to a gene.

11.3 Complex Assemblies of Proteins Control Eukaryotic Transcription (2 of 2)

Checkpoint question What must occur before RNA polymerase can bind to a promoter and transcribe a specific eukaryotic gene?

Transcription factors must bind to enhancers to facilitate the attachment of RNA polymerase to the promoter.

Figure 11.3



Enhancers
Promoter
Gene
DNA
Transcription factors
Activator proteins
Other proteins
DNA-bending protein
RNA polymerase
Bending of DNA
Transcription

11.4 Eukaryotic RNA May Be Spliced in More Than One Way (2 of 2)

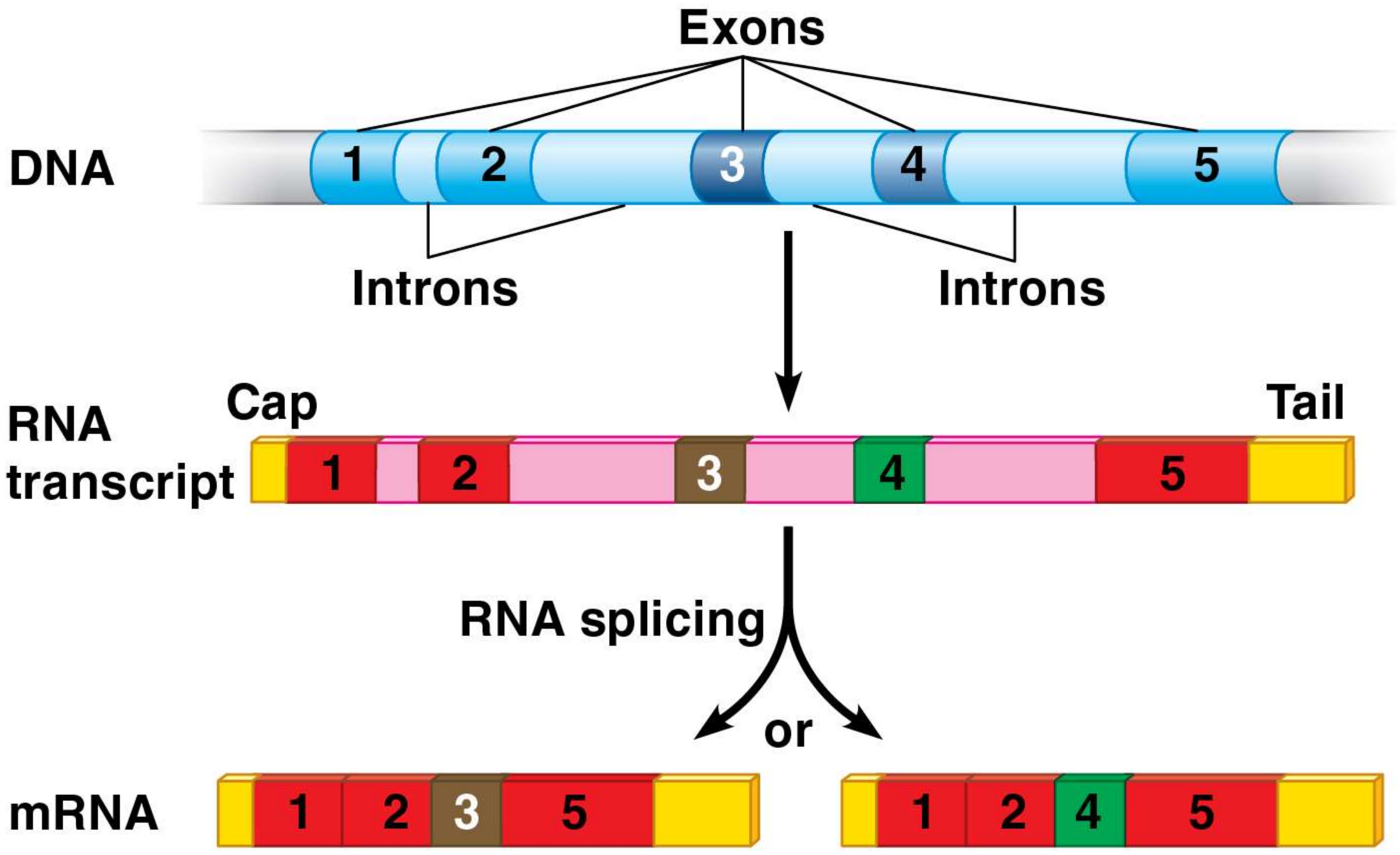
Checkpoint question How is it possible that just under 21,000 human genes can produce more than 100,000 polypeptides?

Through alternate splicing: Each kind of polypeptide is encoded by an mRNA molecule containing a different combination of exons.

11.4 Eukaryotic RNA May Be Spliced in More Than One Way (1 of 2)

- After transcription, **alternative RNA splicing** may generate two or more types of m RNA from the same transcript.
- In humans, more than 90% of protein-coding genes appear to undergo alternate splicing.

Figure 11.4_3

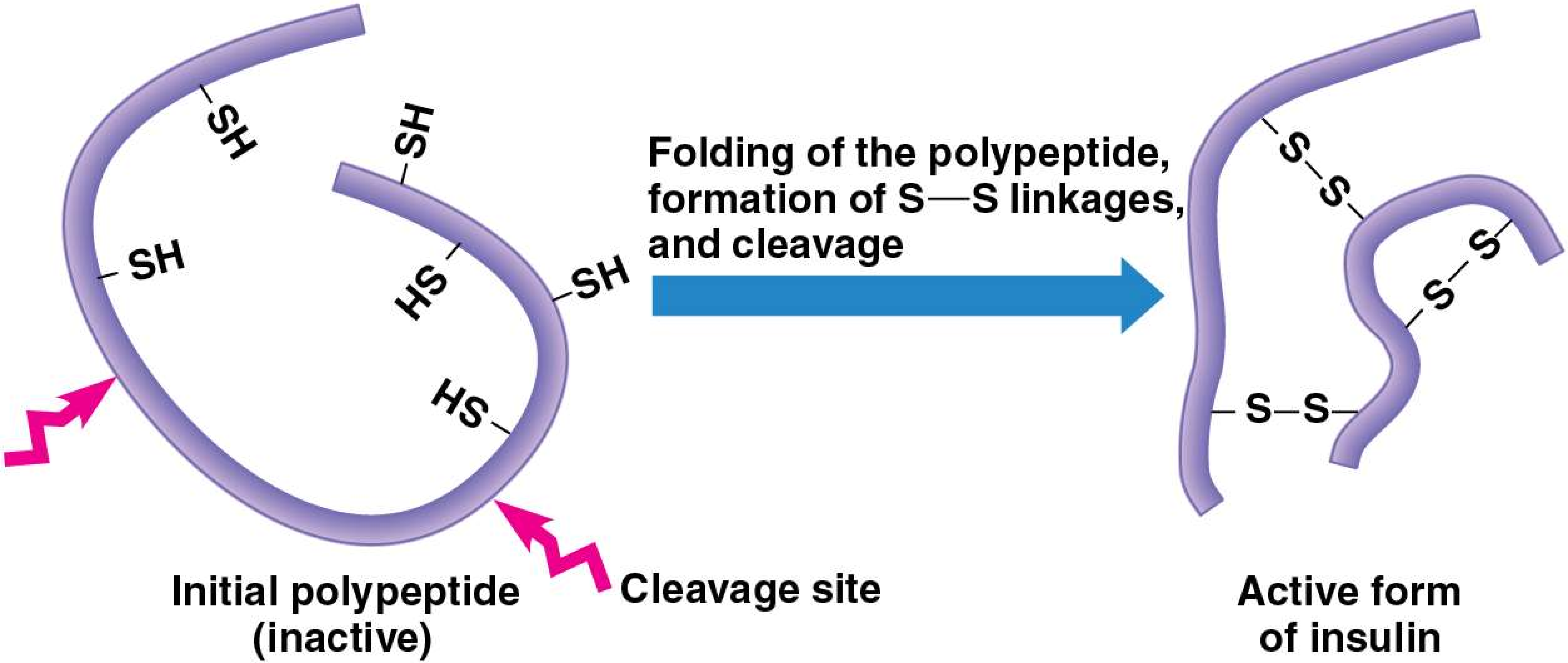


Exons
DNA
1
2
3
4
5
Introns
Introns
Cap
Tail
RNA transcript
1
2
3
4
5
RNA splicing
or
mRNA
1
2
3
5
1
2
4
5

11.5 Later Stages of Gene Expression Are Also Subject to Regulation (1 of 2)

- The lifetime of an mRNA molecule helps determine how much protein is made, as do factors involved in translation.
- A protein may need to be activated in some way, and eventually the cell will break it down.

11.5 Later Stages of Gene Expression Are Also Subject to Regulation (2 of 2)



Checkpoint question Review Figure 11.5. If the enzyme responsible for cleaving inactive insulin is deactivated, what effect will this have on the form and function of insulin?

The final molecule will have a shape different from that of active insulin and therefore will not be able to function as a hormone.

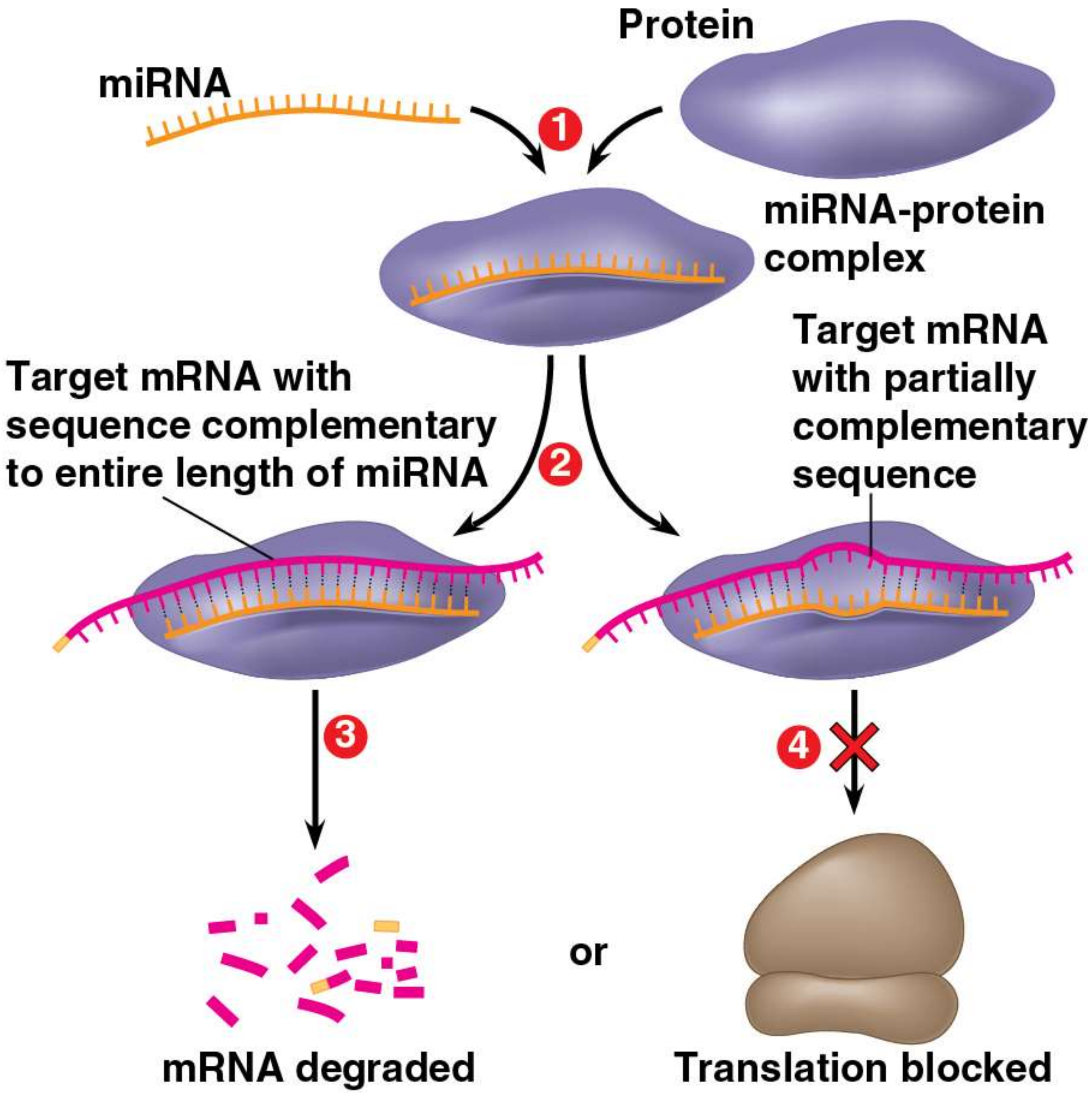
11.6 Noncoding RNAs Play Multiple Roles in Controlling Gene Expression (1 of 3)

- Only 1.5% of the human genome codes for proteins. (This is also true of many other multicellular eukaryotes.)
- Another small fraction of DNA consists of genes for ribosomal RNA and transfer RNA.

11.6 Noncoding RNAs Play Multiple Roles in Controlling Gene Expression (2 of 3)

- A flood of recent data suggests that a significant amount of the remaining genome is transcribed into functioning but non-protein-coding RNAs.
- A variety of small RNA molecules, when bound to proteins, can prevent gene expression by pairing with an mRNA molecule and either degrading it or blocking translation.

Figure 11.6_3



Protein
miRNA
1
miRNA-protein complex
Target mRNA with sequence complementary to entire length of miRNA
2
Target mRNA with partially complementary sequence
3
4
or
mRNA degraded
Translation blocked

11.6 Noncoding RNAs Play Multiple Roles in Controlling Gene Expression (3 of 3)

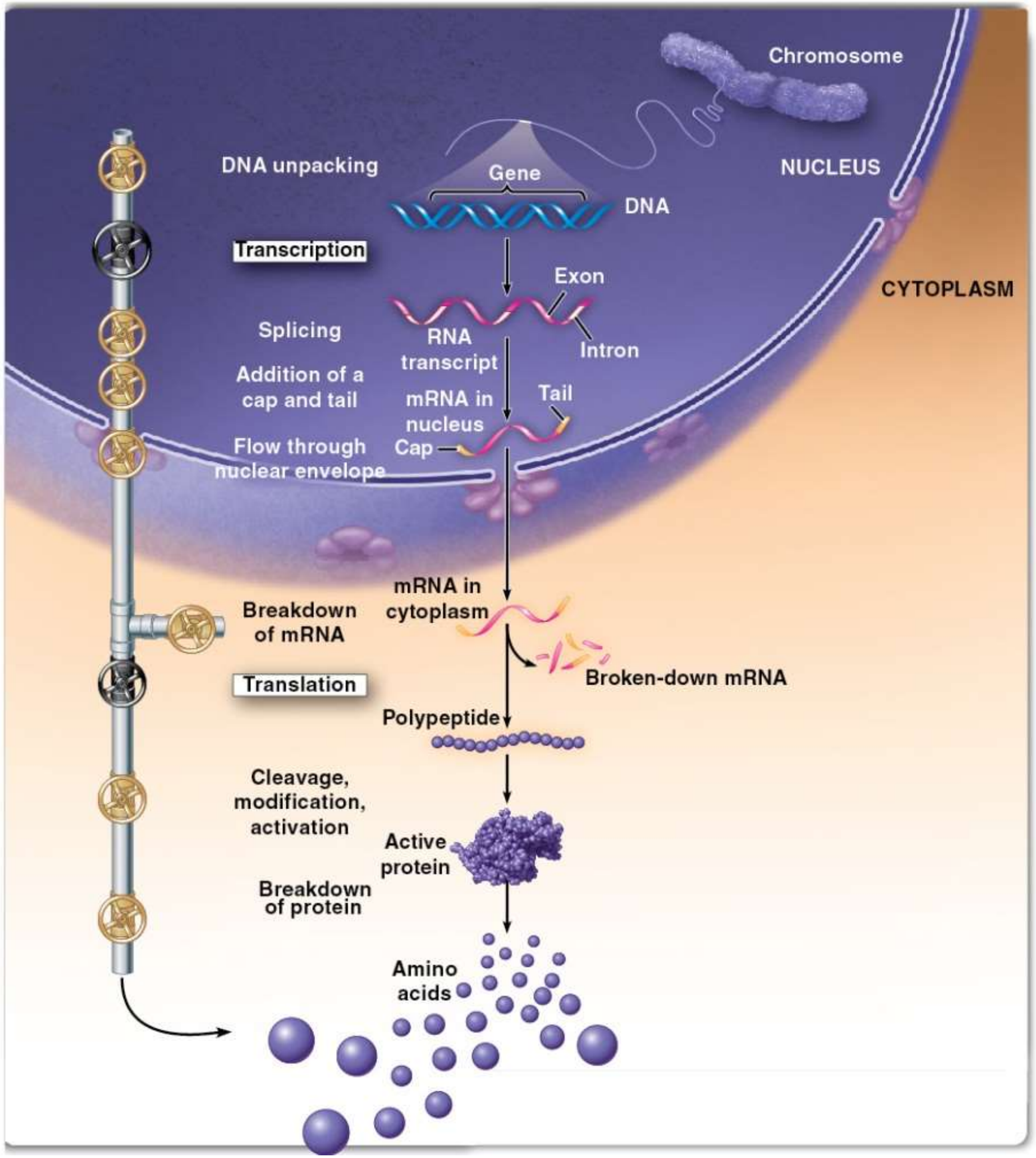
Checkpoint question If a gene has the sequence AATTCGCG, what would be the sequence of an miRNA that turns off the gene?

The gene will be transcribed as the mRNA sequence UUAAGCGC; an miRNA of sequence AAUUCGCG would bind to and disable this mRNA.

11.7 Visualizing the Concept: Multiple Mechanisms Regulate Gene Expression in Eukaryotes (1 of 2)

- Gene expression can be regulated multiple ways within both the nucleus and cytoplasm.

Figure 11.7_8



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11.7 Visualizing the Concept: Multiple Mechanisms Regulate Gene Expression in Eukaryotes (2 of 2)

Checkpoint question Of the nine regulatory “valves” shown here, which five can also operate in a prokaryotic cell?

Control of (1) transcription; (2) mRNA breakdown; (3) translation; (4) protein activation; and (5) protein breakdown

11.8 Fruit Fly Development Provides an Opportunity to Examine Gene Expression

- A series of RNAs and proteins produced in the embryo control the development of an animal from a fertilized egg.
- A **homeotic gene** is a master control gene that regulates groups of other genes that determine the anatomy of parts of the body, such as which body parts will develop where in a fly.

Figure 11.8a

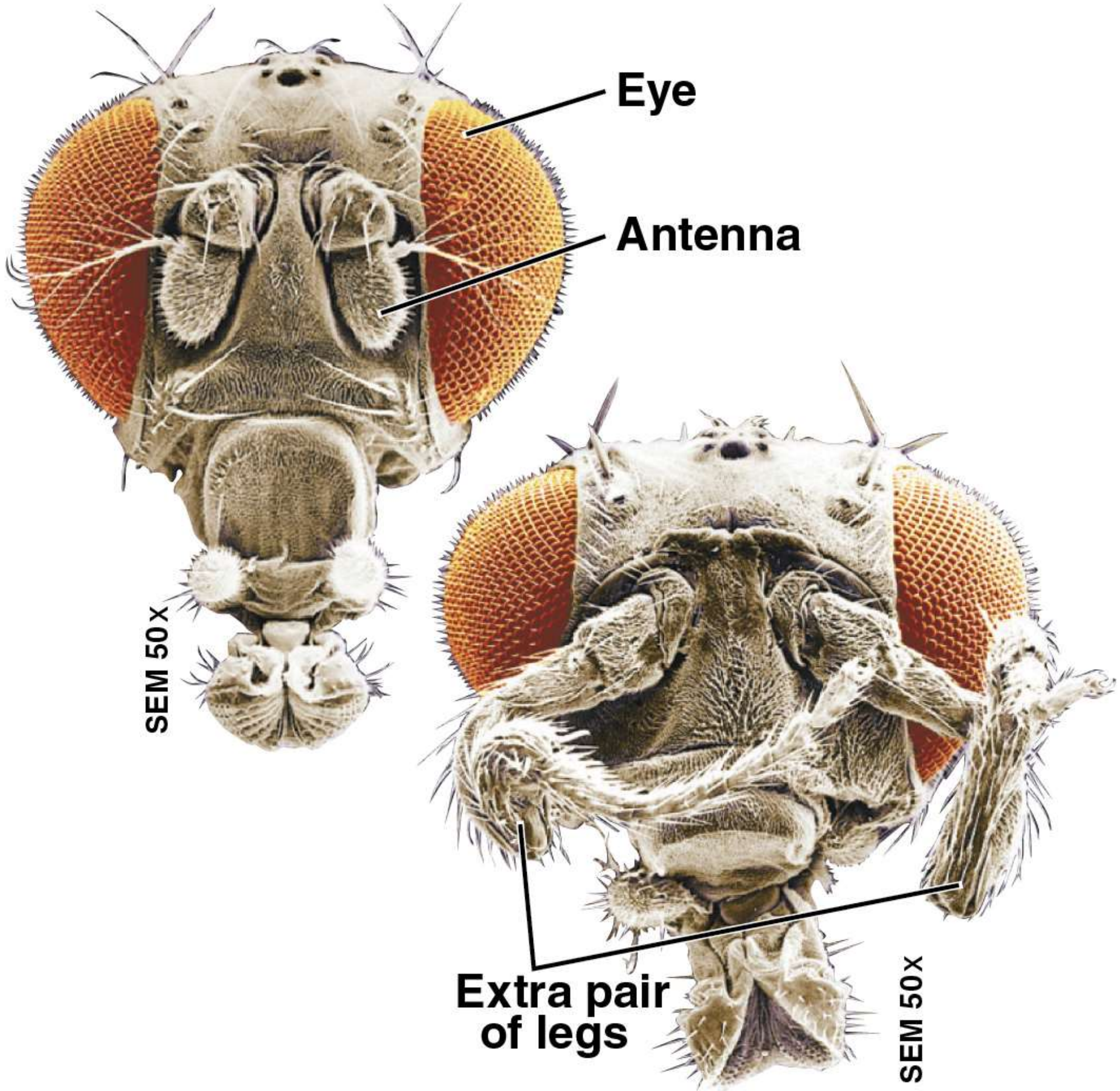

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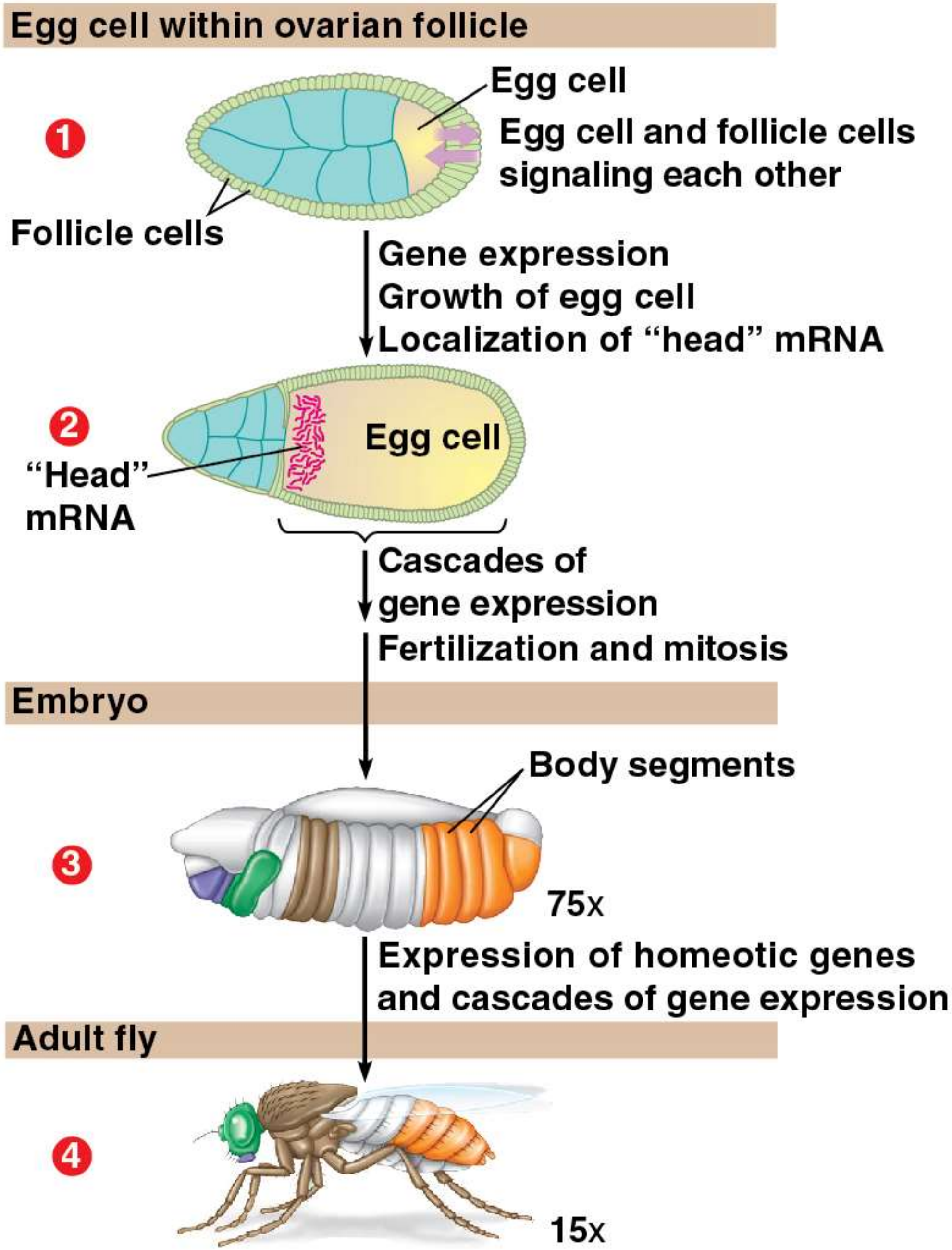
Figure 11.8b_3



11.9 Connection: Researchers Can Monitor the Expression of Specific Genes (1 of 2)

- Scientists can use various techniques to study how genes work together.
  - **Nucleic acid hybridization** allows researchers to identify cells in which a target gene is expressed.
  - A **DNA microarray** can gather data about which genes are turned on or off in a particular cell.

Figure 11.9a

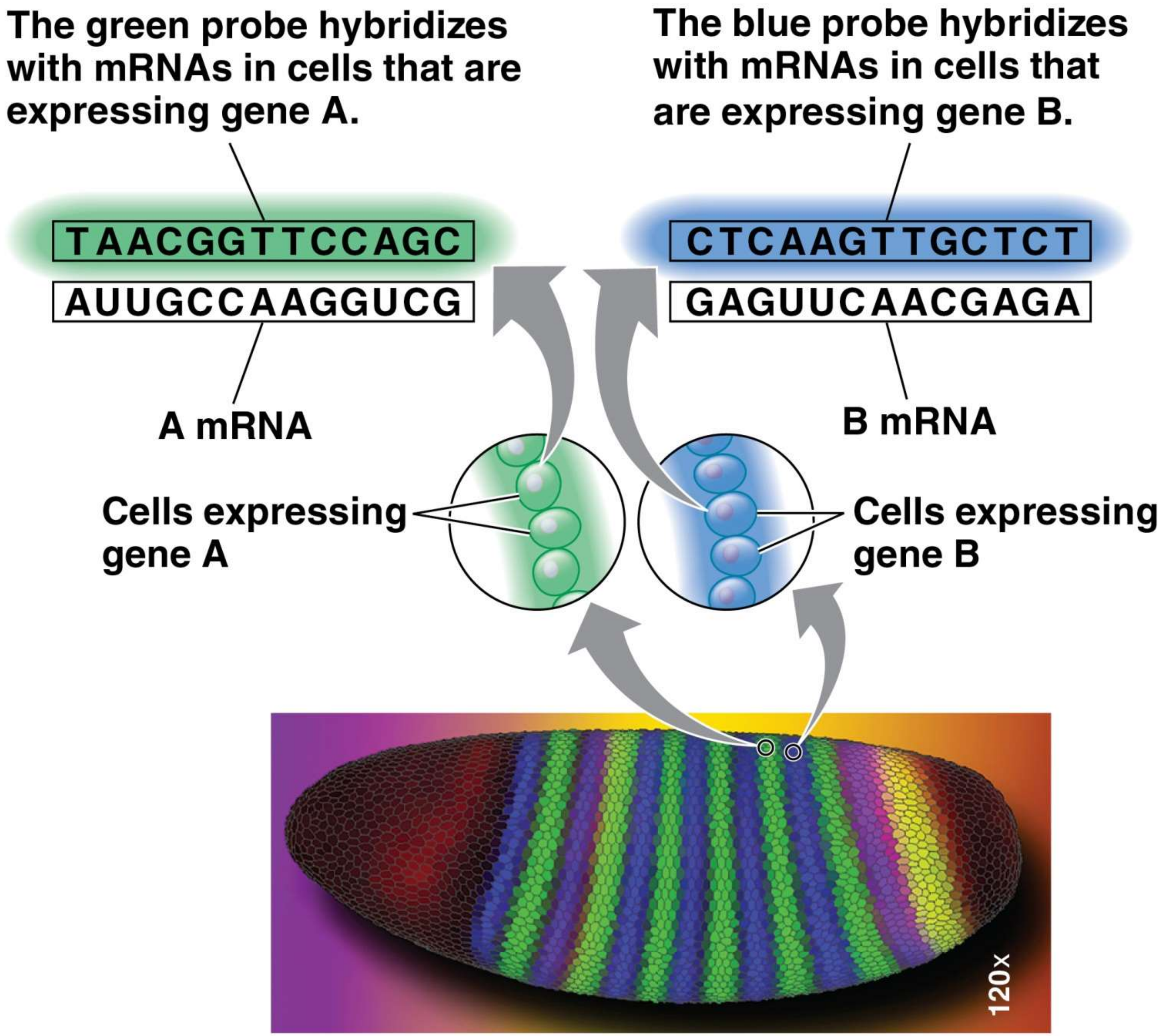
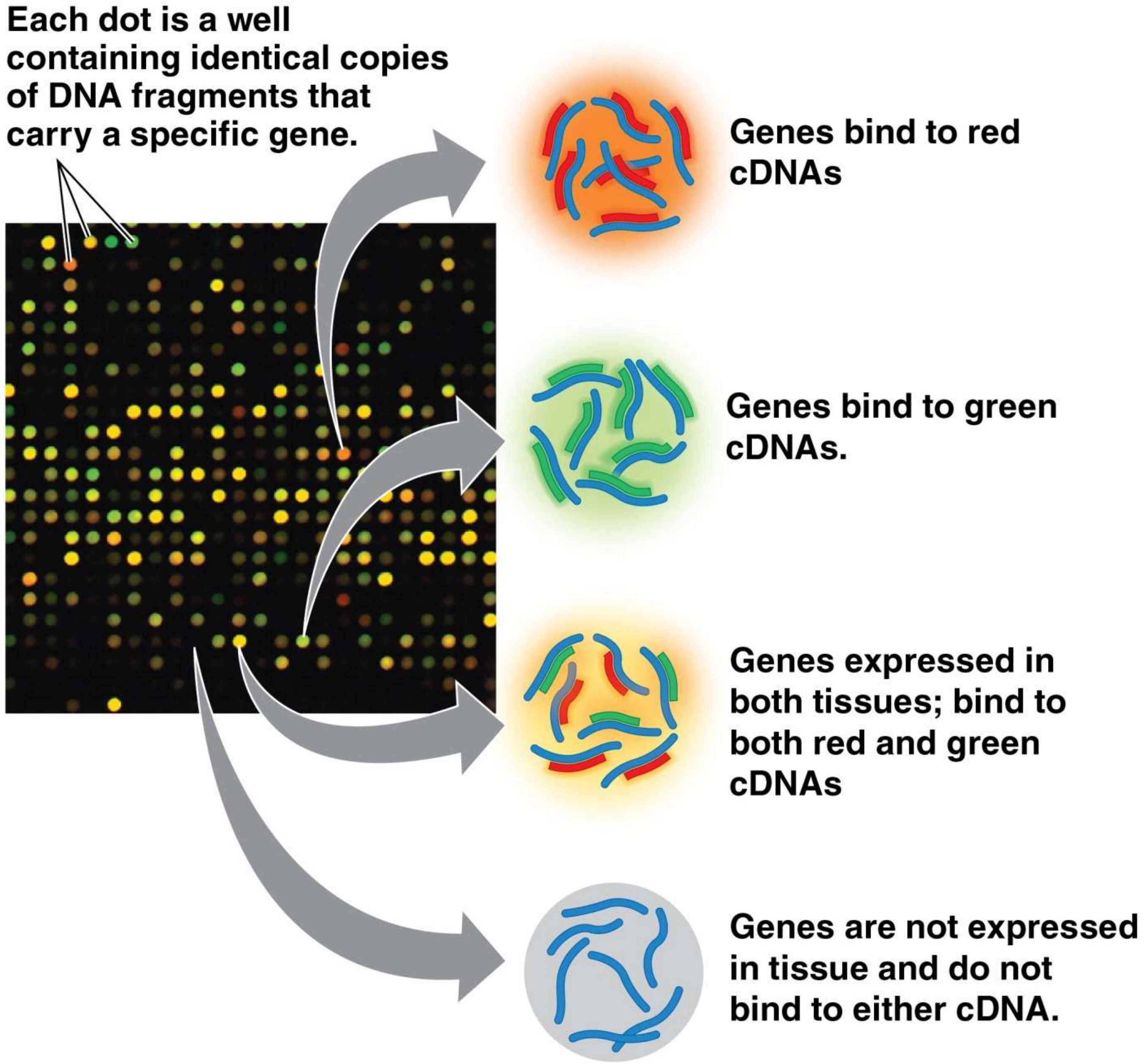

The green probe hybridizes with mRNAs in cells that are expressing gene A.
The blue probe hybridizes with mRNAs in cells that are expressing gene B.
TAACGGTTCCAGC
AUUGCCAAGGUCG
CTCAAGTTGCTCT
GAGUUCAACGAGA
A mRNA
B mRNA
Cells expressing gene A
Cells expressing gene B
120x

Figure 11.9b


Each dot is a well containing identical copies of DNA fragments that carry a specific gene.
Genes bind to red cDNAs
Genes bind to green cDNAs.
Genes expressed in both tissues; bind to both red and green cDNAs
Genes are not expressed in tissue and do not bind to either cDNA.

11.9 Connection: Researchers Can Monitor the Expression of Specific Genes (2 of 2)

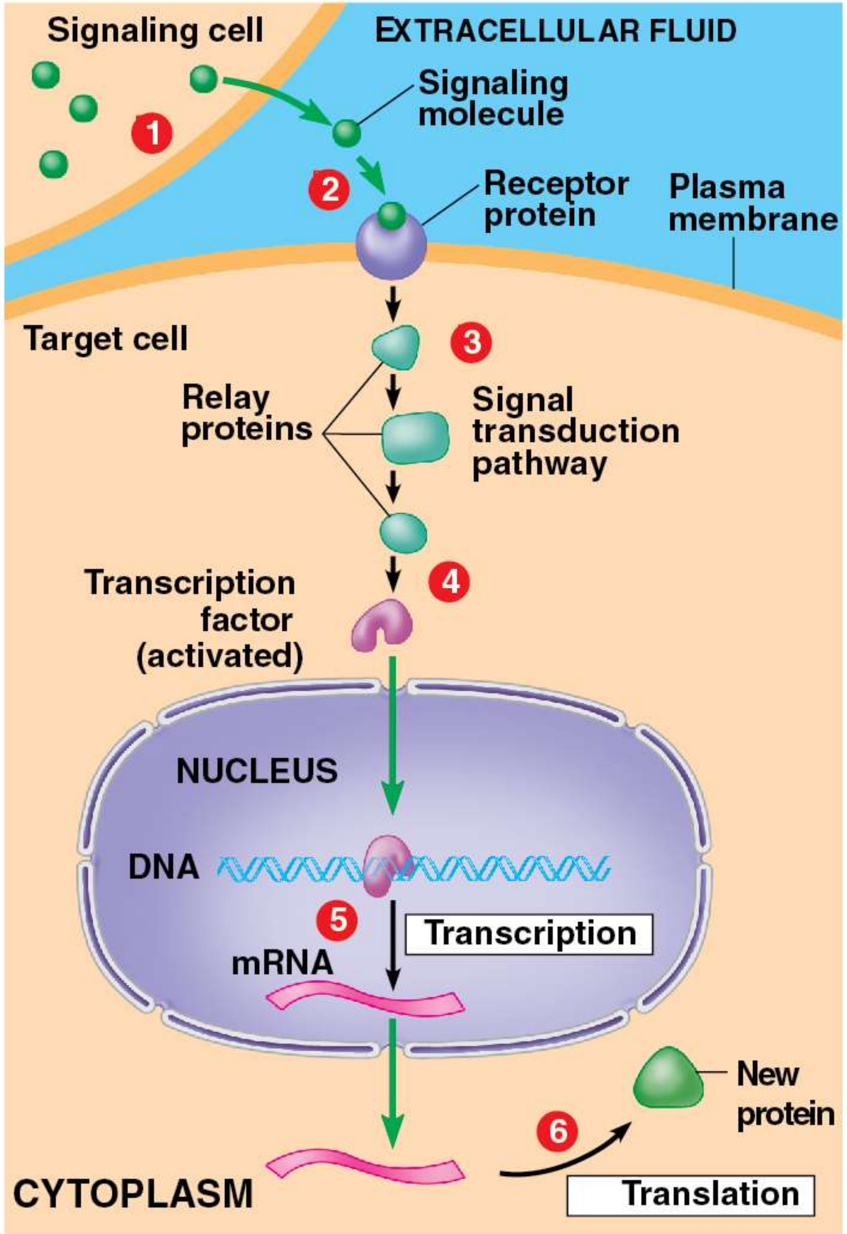
Checkpoint question What can be learned from a DNA microarray?

Which genes are active (transcribed) in a particular sample of cells

11.10 Cells Respond to Their Neighboring Cells with Changes in Gene Expression (1 of 2)

- Cell-to-cell signaling via proteins or other kinds of molecules carrying messages from signaling cells to receiving (target) cells is an important mechanism in the coordination of cellular activities.
  - In most cases, a signaling molecule acts by binding to a receptor protein in the plasma membrane.
  - A **signal transduction pathway** is a series of molecular changes that converts a signal on a target cell's surface to a specific response inside the cell.

Figure 11.10


Signaling cell
EXTRACELLULAR FLUID
1
Signaling molecule
2
Receptor protein
Plasma membrane
Target cell
3
Relay proteins
Signal transduction pathway
Transcription factor (activated)
4
NUCLEUS
DNA
5
Transcription
mRNA
New protein
6
CYTOPLASM
Translation

11.10 Cells Respond to Their Neighboring Cells with Changes in Gene Expression (2 of 2)

Checkpoint question To turn on a gene, must a signal molecule actually enter a target cell?

No; a signal molecule can bind to a receptor protein in the outer membrane of the target cell and trigger a signal transduction pathway that activates transcription factors.

11.11 Evolution Connection: Cell-Signaling Systems Appeared Early in the Evolution of Life

- Similarities among organisms suggest that signal transduction pathways evolved early in the history of life on Earth.

Checkpoint question In what sense is the joining of yeast mating types “sex”?

The process results in the creation of a diploid cell that is a genetic blend of two parental haploid cells.

Cloning of Plants and Animals

11.12 Plant Cloning Shows That Differentiated Cells May Retain all of Their Genetic Potential (1 of 2)

- A **clone** is an individual organism created by asexual reproduction and thus genetically identical to a single parent.
- Any cell capable of producing every kind of specialized cell in an organism is said to be **totipotent**.
- **Regeneration**, the regrowth of lost body parts, demonstrates that differentiation need not impair an animal cell's genetic potential.

11.12 Plant Cloning Shows That Differentiated Cells May Retain all of Their Genetic Potential (2 of 2)

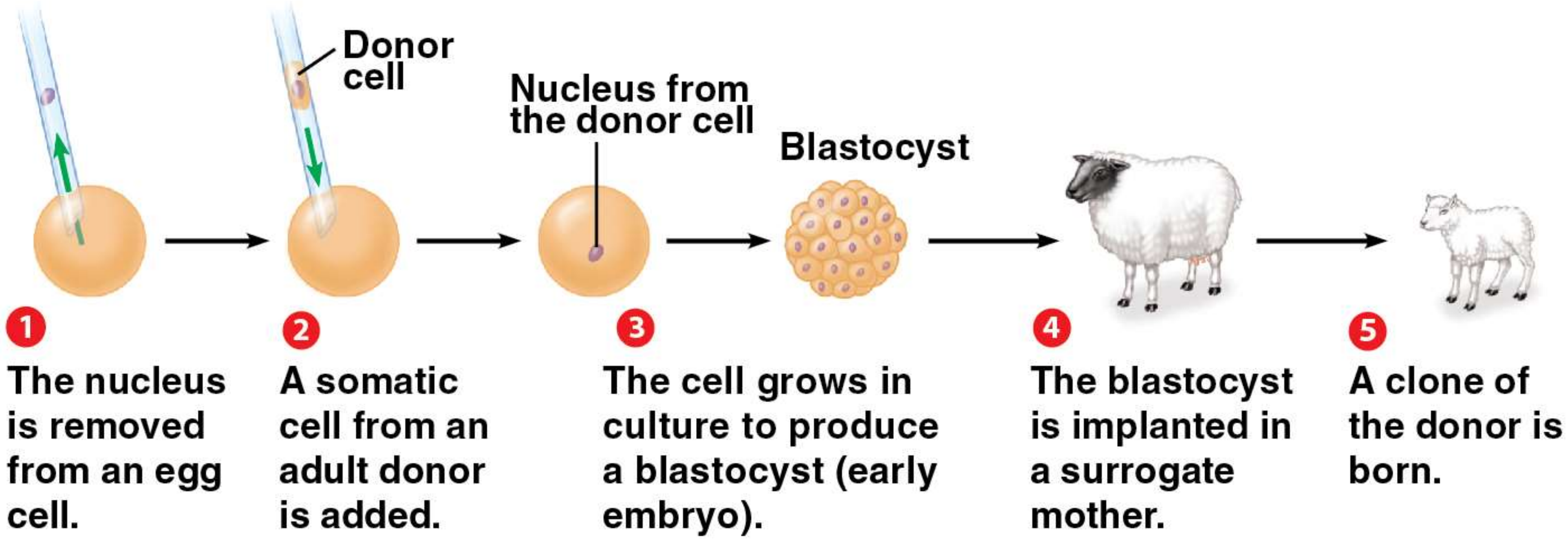
Checkpoint question How does the cloning of plants from differentiated cells support the view that differentiation is based on the control of gene expression rather than on irreversible changes in the genome?

Cloning shows that all the genes of a fully differentiated plant cell are still present.

11.13 Scientific Thinking: Biologists can Clone Animals via Nuclear Transplantation (1 of 2)

- In the process of animal cloning called **nuclear transplantation**, DNA from a donor cell is inserted into a nucleus-free host egg, resulting in a clone of the DNA donor.
- If the animal being cloned is a mammal, the blastocyst is then implanted into the uterus of a surrogate mother. This type of cloning is called **reproductive cloning** because it can result in the birth of a new living individual.

Figure 11.13_5



Pearson

11.13 Scientific Thinking: Biologists Can Clone Animals via Nuclear Transplantation (2 of 2)

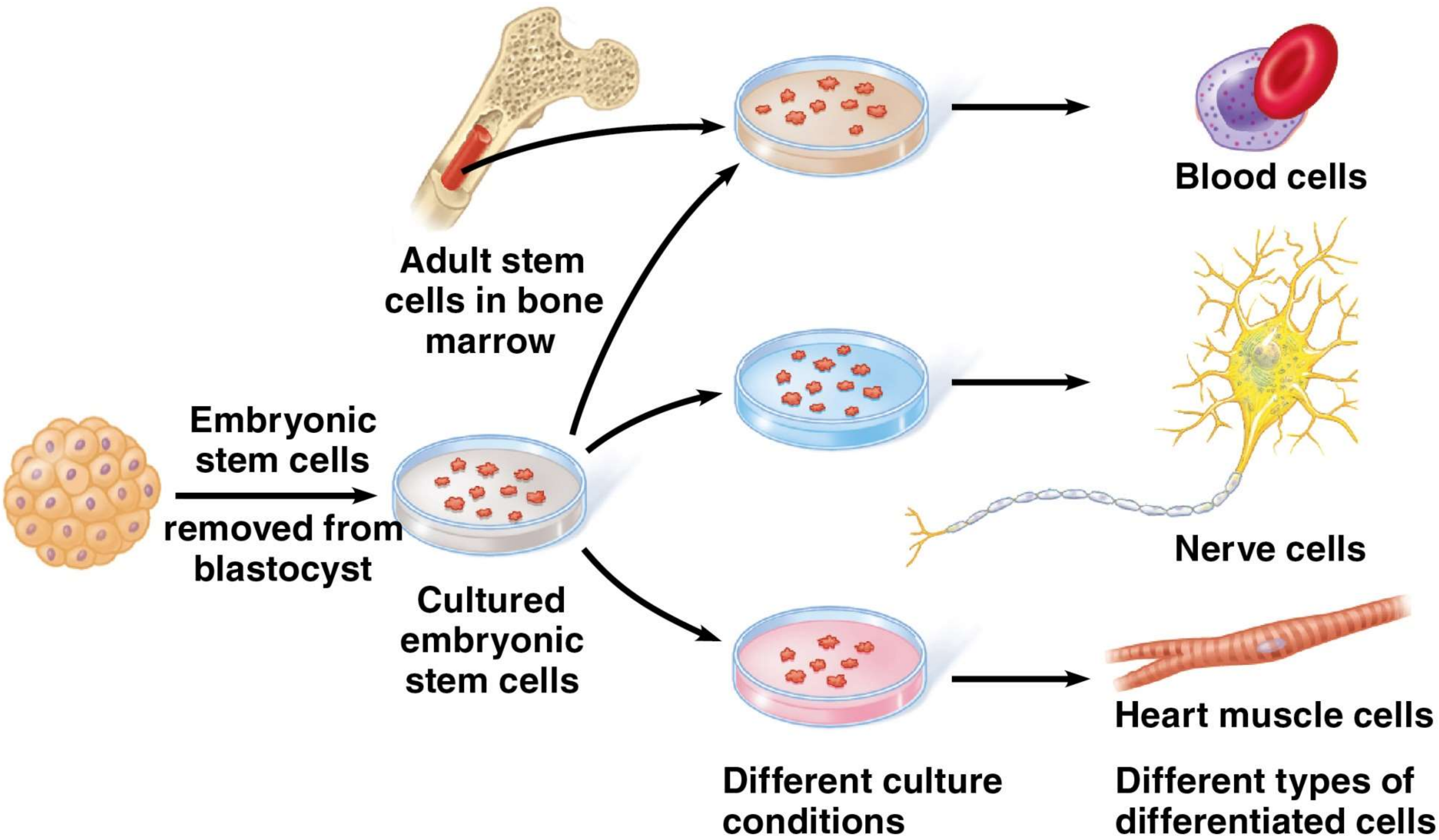
Checkpoint question Why does the history of cloning sheep suggest human cloning should not be pursued?

It took hundreds of failures to achieve a single success with Dolly. Such experimentation with humans raises ethical questions.

11.14 Connection: Therapeutic Cloning Can Produce Stem Cells with Great Medical Potential (1 of 2)

- The goal of **therapeutic cloning** is to produce **embryonic stem cells**.
  - Such cells may eventually be used for a variety of therapeutic purposes.
  - Like embryonic stem cells, **adult stem cells** can both perpetuate themselves in culture and give rise to differentiated cells.
  - Unlike embryonic stem cells, adult stem cells normally give rise to only a limited range of cell types.

Figure 11.14


Adult stem cells in bone marrow
Embryonic stem cells
removed from blastocyst
Cultured embryonic stem cells
Blood cells
Nerve cells
Heart muscle cells
Different culture conditions
Different types of differentiated cells

11.14 Connection: Therapeutic Cloning Can Produce Stem Cells with Great Medical Potential (2 of 2)

Checkpoint question In nature, how do embryonic stem cells differ from adult stem cells?

Embryonic cells give rise to all the different kinds of cells in the body. Adult stem cells generate only a few related types of cells.

The Genetic Basis of Cancer

11.15 Cancer Results from Mutations in Genes That Control Cell Division

- Cancer cells, which divide uncontrollably, result from mutations in genes whose protein products affect the cell cycle.
  - A mutation can change a **proto-oncogene**, a normal gene that helps control cell division, into an **oncogene**, which causes cells to divide excessively.
  - Mutations that inactivate **tumor-suppressor genes** can also lead to cancer.

Figure 11.15a

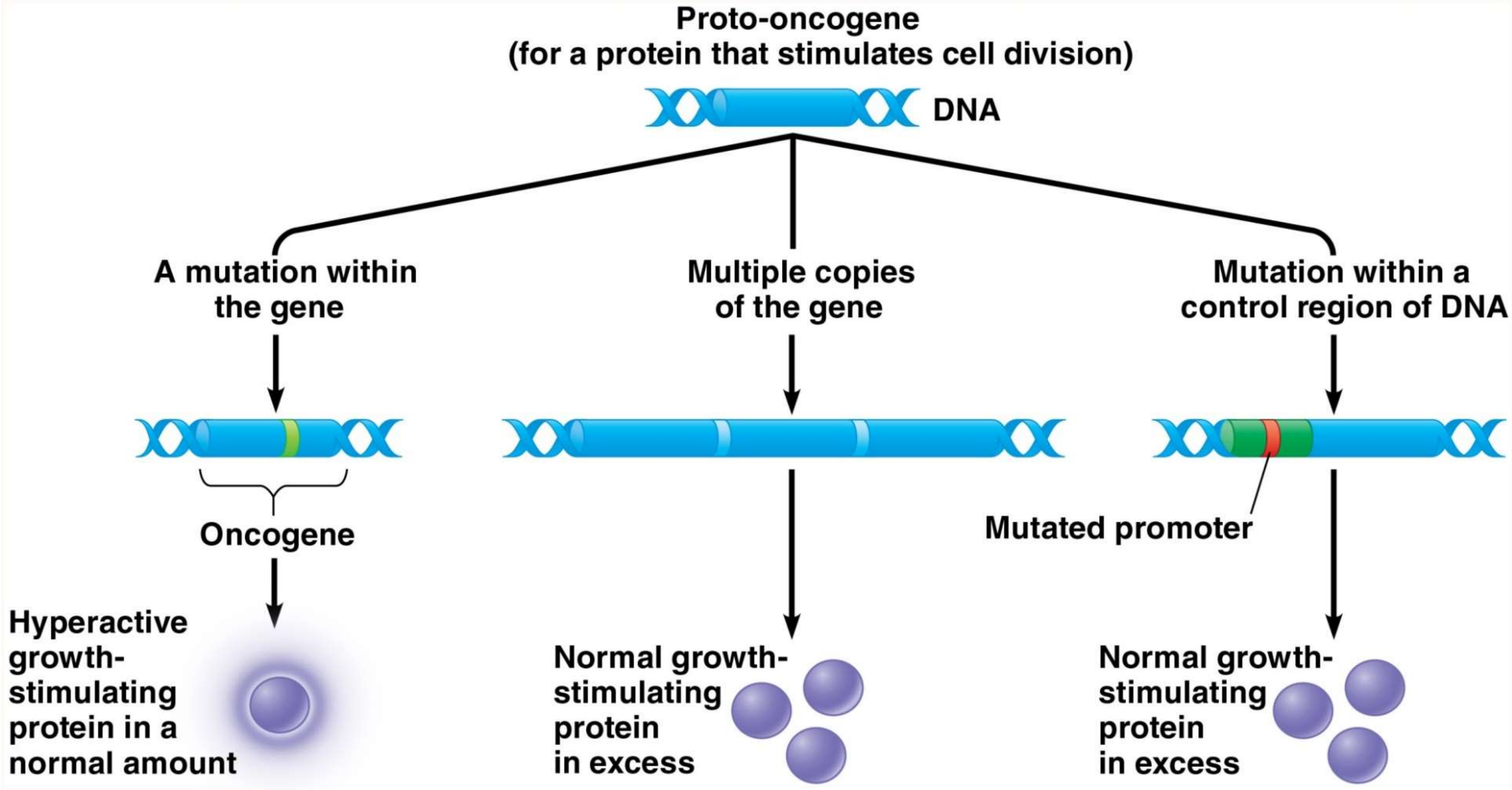
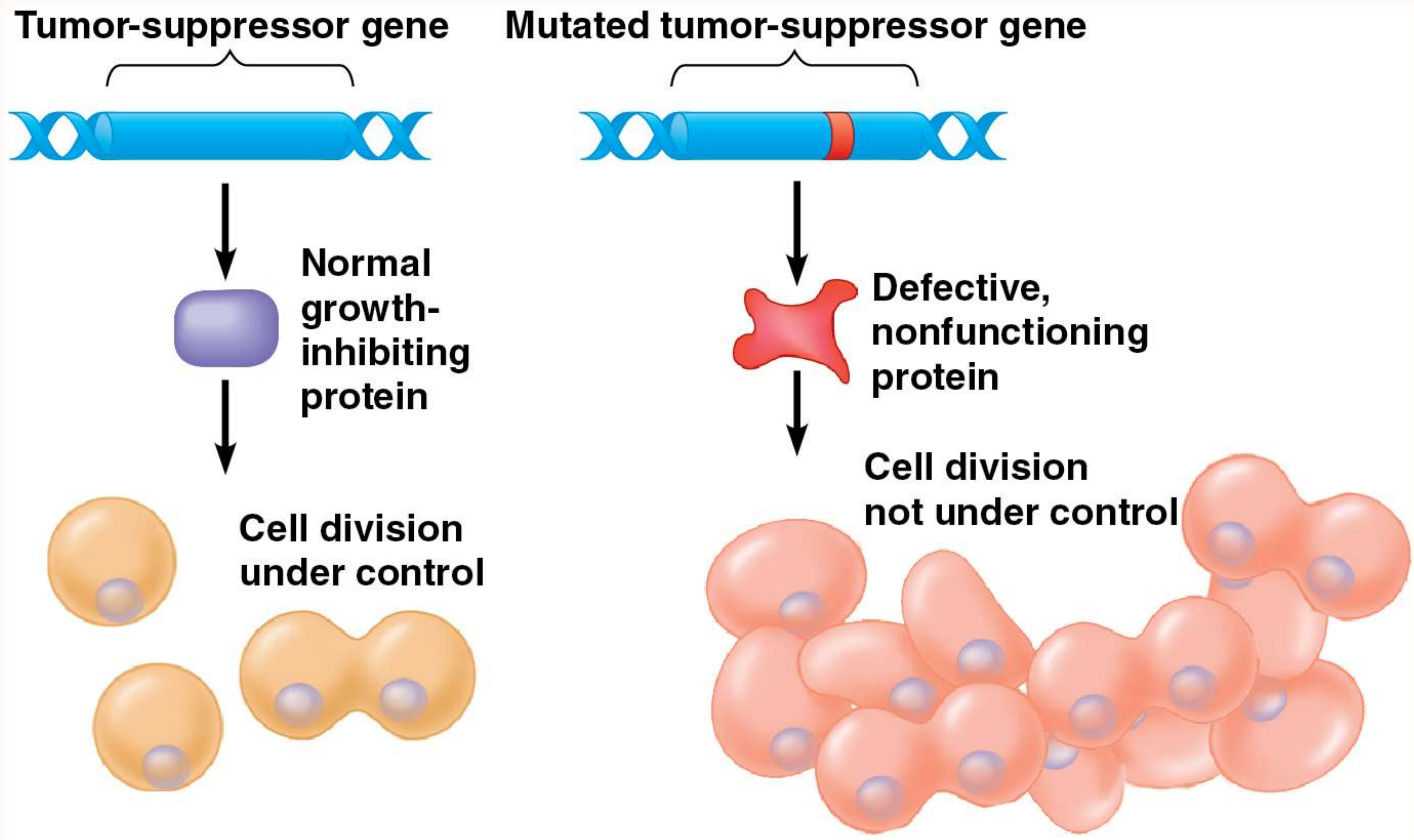


Figure 11.15b



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11.16 Multiple Genetic Changes Underlie the Development of Cancer (1 of 2)

- Cancers result from a series of genetic changes.
- Colon cancer illustrates the gradual progression from somatic mutation to cancer.

Figure 11.16a_3

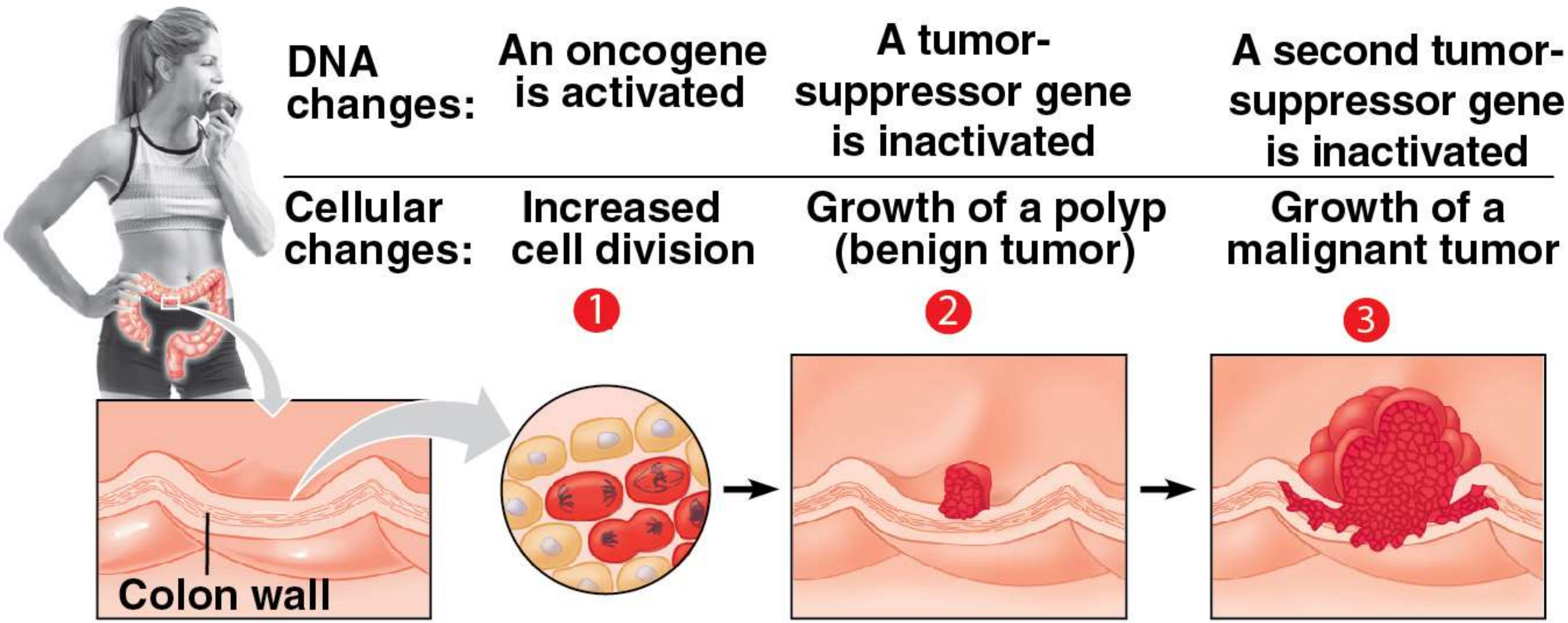
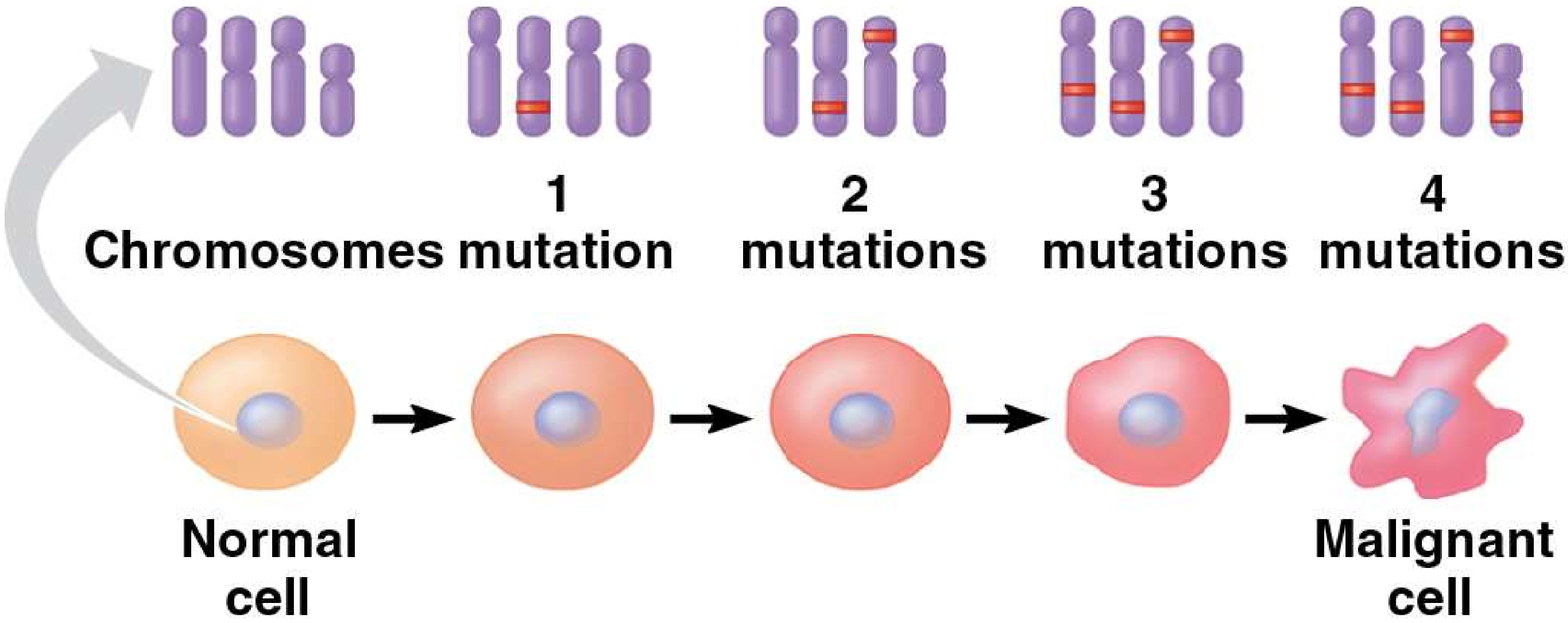


Figure 11.16b



11.16 Multiple Genetic Changes Underlie the Development of Cancer (2 of 2)

Checkpoint question Epithelial cells, those that line body cavities, are frequently replaced and so divide more often than most other types of body cells. Will epithelial cells become cancerous more or less frequently than other types of body cells?

More frequent cell divisions may result in more frequent mutations and thus a greater chance of cancer.

11.17 Faulty Proteins Can Interfere with Normal Signal Transduction Pathways (1 of 2)

- Signal transduction pathways lead to the synthesis of proteins that influence the cell cycle.
- Many proto-oncogenes and tumor-suppressor genes code for proteins active in signal transduction pathways regulating cell division.

Figure 11.17a

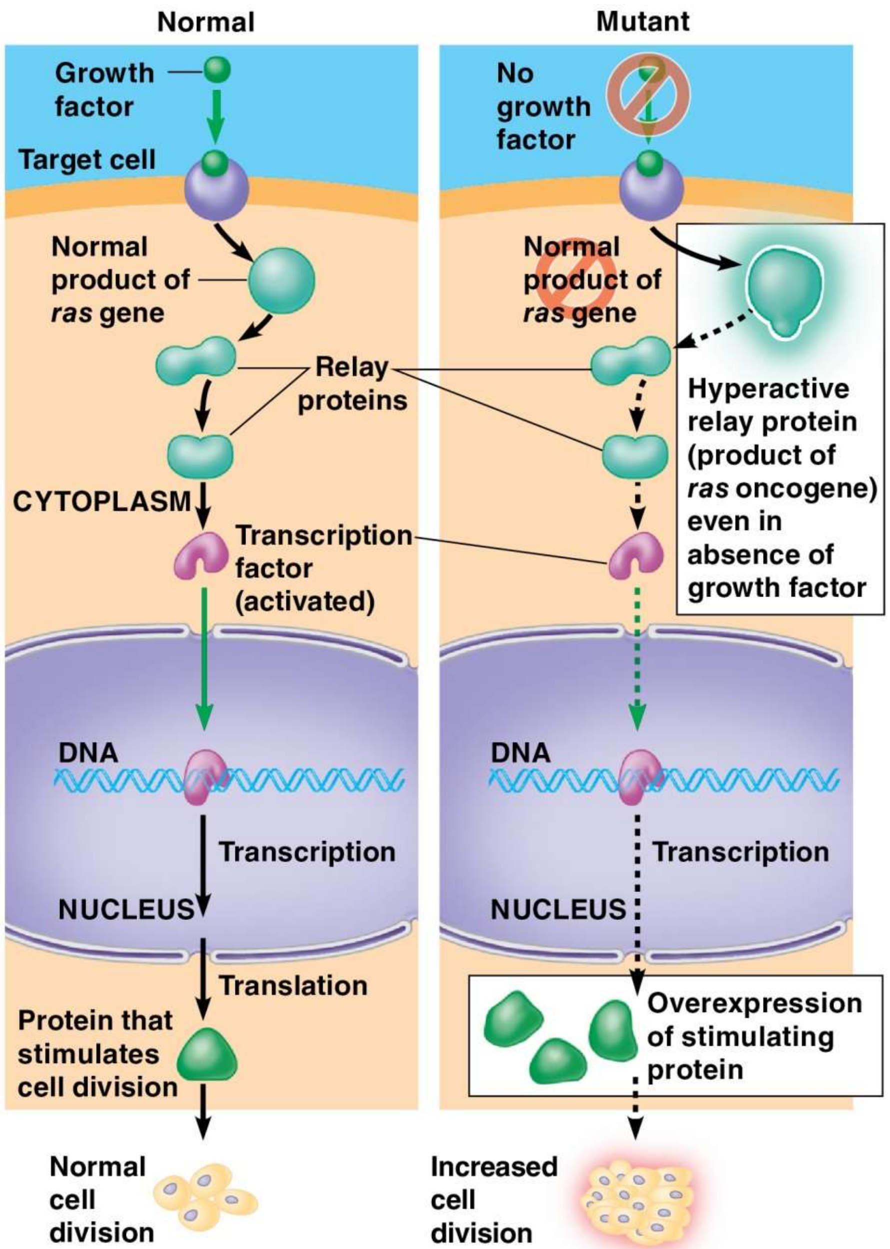
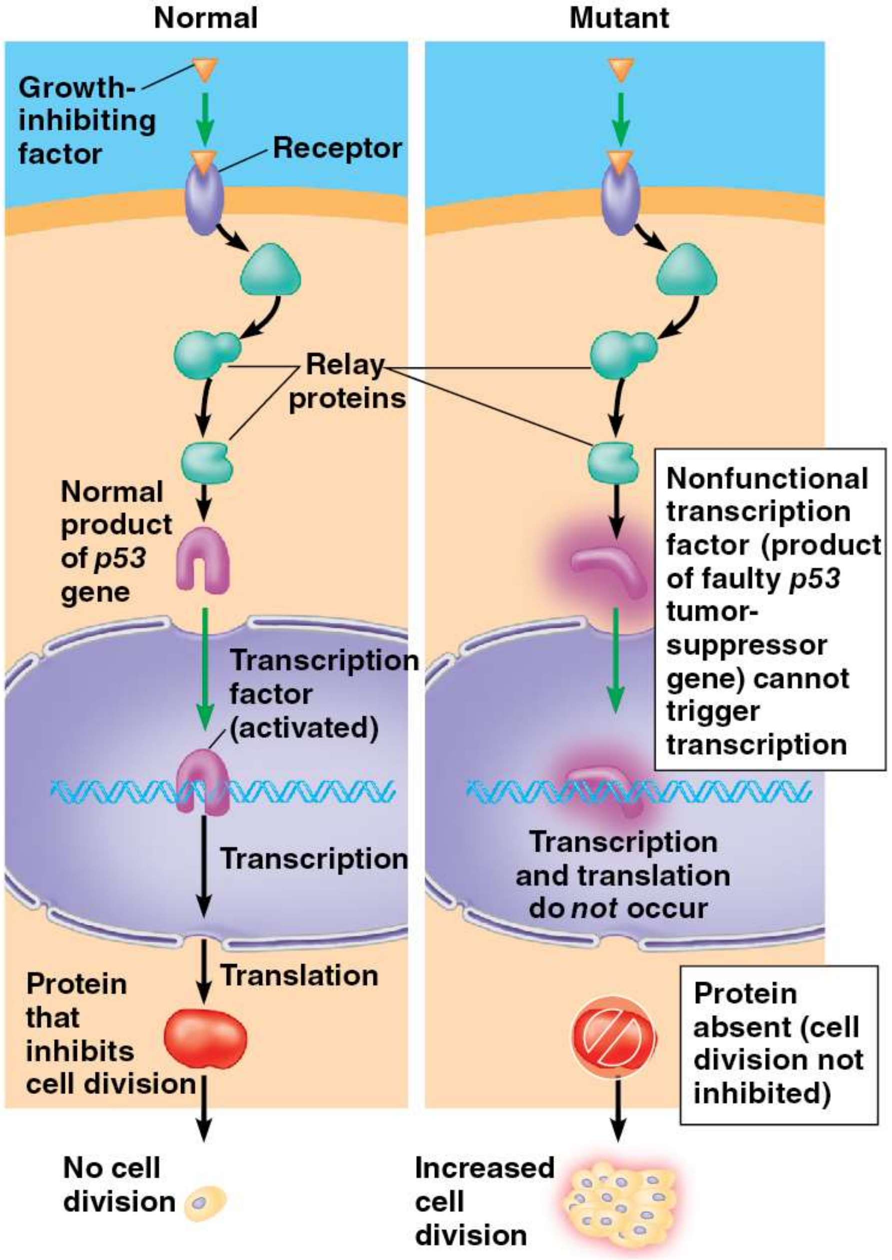


Figure 11.17b



11.17 Faulty Proteins Can Interfere with Normal Signal Transduction Pathways (2 of 2)

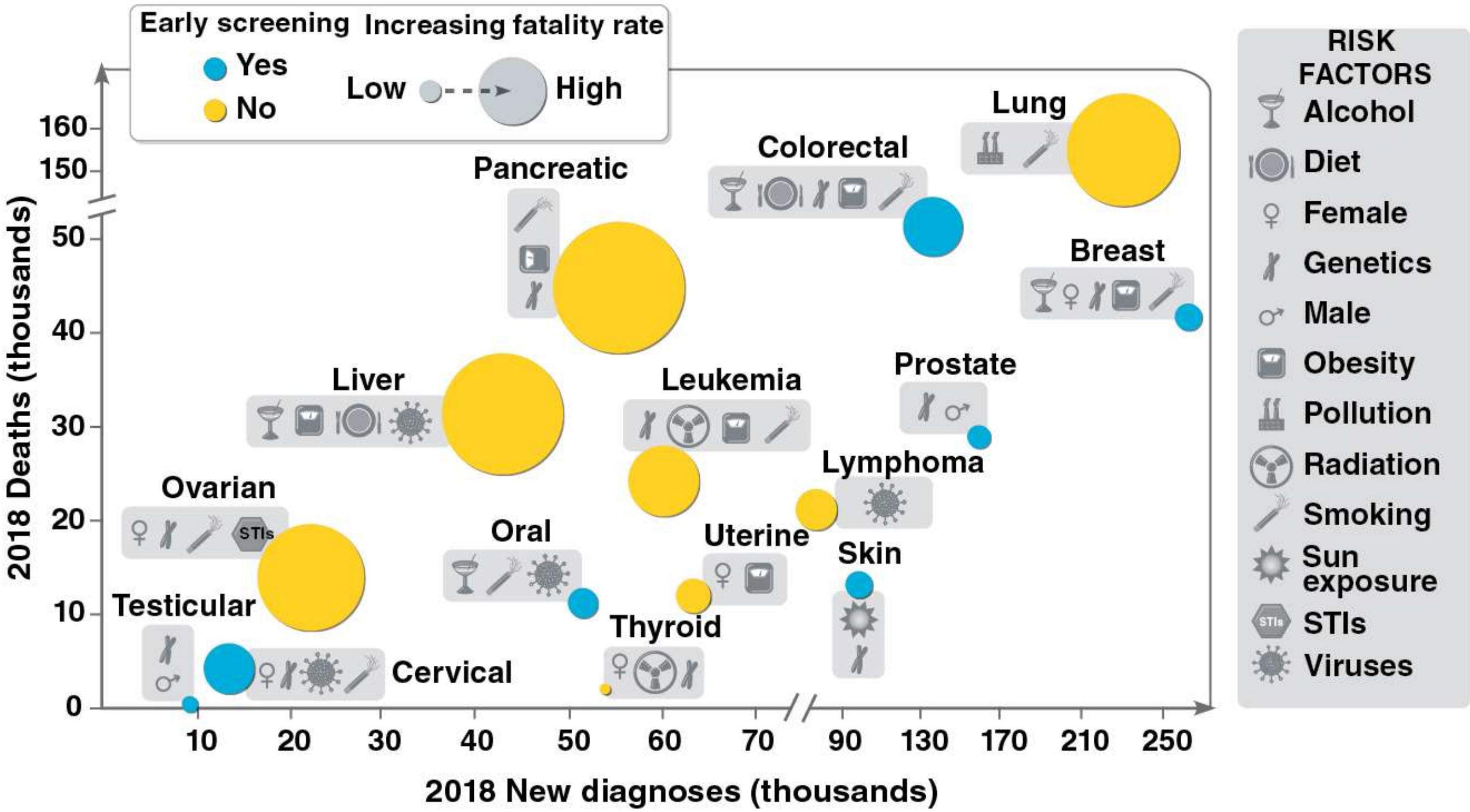
Checkpoint question Contrast the action of an oncogene with that of a cancer-causing mutation in a tumor-suppressor gene.

An oncogene encodes an abnormal protein that stimulates cell division via a signal transduction pathway; a mutant tumor-suppressor gene encodes a defective protein unable to function in a pathway that normally inhibits cell division.

11.18 Connection: Lifestyle Choices Can Reduce the Risk of Cancer (1 of 2)

- Cancer is the second-leading cause of death (after heart disease) in most industrialized nations.
- Most cancers arise from mutations caused by environmental factors. Agents that alter DNA and make cells cancerous are called **carcinogens**.
- Reducing exposure to carcinogens and making other lifestyle choices can help reduce cancer risk.

11.18 Connection: Lifestyle Choices Can Reduce the Risk of Cancer (2 of 2)



Checkpoint question Looking at the data presented in Figure 11.18, which type of screenable cancer kills the most people?