UN2005/UN2401 '18 -- Lecture 17 -- Edited 11/6/18 (Problems to do are indicated in **red bold.**)

You will need Handouts 16A & 16B.(See handout List) We will not get to Handouts 17A & B. Extra paper copies are or will be in the boxes on 7th floor of Mudd after the PM class.

I. Intro to Regulation in Prokaryotes = Handout 16A. See topic III in notes for Lecture 16 for A-C.

A. Why Regulation of enzyme synthesis is reasonable and/or necessary.

B. The Phenomenon

C. Summary of Terminology

D. Feedback Inhibition vs Repression -- Why do you need both types of regulation? See handout 16A. Factors to consider:

- Speed (inhibition is faster)
- Which enzymes are affected (first in pathway in feed back. inhibition vs all enzymes of pathway in repression)
- What is changed -- enzyme activity (in inhibition) vs synthesis of enzymes or ***gene*** activity or gene expression (in repression)

Overall, have coarse control (repression/induction) vs fine control (inhibition/activation). See chart and picture on bottom half of handout 16A. See also Sadava fig. 16.3.

Note: Enzyme activation and induction can be compared in a similar way -- Activation increases enzyme activity while induction turns on enzyme synthesis.

II. Mechanism of Prokaryote Regulation of Enzyme Synthesis (Operons)

Note: This mechanism was largely figured out by analyzing mutants. How it was done is fascinating, but complex, so we will explain the mechanism first, and then you can try your hand at predicting the effects of mutations. See E below for more details, and problem set 12 for examples.

A. How is co-ordinate control achieved? Upper Left Panel on handout -- idea of cluster or operon. See Sadava fig. 16.4 or Becker fig. 20-2 (23-2).

1. Genes regulated together are linked -- genes to be controlled co-ordinately (turned on and off together) are next to each other on the DNA. The cluster of structural (protein coding) genes (plus linked regulator sequences explained below) is called an operon.

2. ,One Promoter per operon. All the genes in a cluster share a single promoter. Therefore the linked genes are transcribed as a unit to give one single mRNA . One mRNA is made per operon (not one mRNA per gene). (Note: the promoter is a double stranded DNA sequence that binds RNA polymerase. RNA pol. does not just bind to the transcribed strand.)

3. Polycistronic mRNA. An mRNA able to code for several peptides (such as the mRNA that comes from an entire operon) is called polycistronic mRNA. (cistron = another term for gene).

4. Transcriptional Control -- Regulation is at level of transcription.
The level of protein synthesis is controlled by controlling the level of transcription of the gene coding for the protein(s). The production of mRNA is the only step that is regulated. There is no direct control of translation -- no control of use or degradation of mRNA.

Since mRNA has a short half life in prokaryotes, regulating mRNA synthesis controls the steady state level of mRNA. Translation per se (and degradation of mRNA) are not regulated here. (In some prok. cases and many euk. cases, these are regulated too.)

5. Parts of an operon. An operon consists of a group of linked structural (protein coding) genes that share common regulatory sites and that are transcribed as a single unit.

a. Linked regulatory sites (such as promoters and operators) are always considered part of the operon.

b. Unlinked genes (such as those for repressor/regulator proteins that affect levels of transcription) are not always considered part of the operon itself. Whether an unlinked gene for a regulator protein is considered part of the operon (or not) is usually clear from context. The roles of the regulatory sites/genes are explained in more detail below.

6. Punctuation. Reminder: DNA replication, transcription, and translation, have different stop and start signals. DNA replication starts at *origins*, transcription starts at **promoters**, and translation begins at **start codons** (AUG). Origins vs. Promoters was covered before. What about promoters vs. start codons?

a. mRNA has UTR's. It has leaders (untranslated region on 5' end before first AUG or 5' UTR) & trailers (untranslated 3' end or 3' UTR).

b. Numbers: Number of transcription starts (Promoters) for a message is one; number of translation starts will be greater than one on a polycistronic mRNA.

c. Translation of a polycistronic mRNA starts at multiple start codons. A ribosome assembles at the first AUG and starts translation. After each peptide is completed, the ribosome may continue down the mRNA to the next start codon and start a new peptide chain. Alternatively, the ribosome may detach (and disassociate into subunits) when it comes to a stop codon. In that case a new ribosome forms at the next start codon and starts translation of the next peptide.

d. A question: does bacterial DNA have more promoters or more start codons?

B. How is Transcription Regulated -- how is transcription of an operon turned on or off? What factors are involved? Upper Right Panel on handout

1. Linked Regulatory sites/genes. Each operon has (at least) two regulatory sites linked to the structural genes, that is, located close by on the same DNA, that affect levels of transcription.

a. Promoter -- binds RNA polymerase; determines how much mRNA can be made when operon is 'on.'

b. Operator -- binds repressor protein; determines to what extent operon is 'on' or 'off.'

For more details on Promoter vs Operator, see 'Analyzing Operons', below.

2. Repressor gene/protein -- Each operon can be shut down by binding of a repressor protein to the operator.

a. Where does the repressor protein come from? There must be a gene that codes for the repressor protein. (Middle and bottom panel of handout.)

b. Where is the repressor gene? The repressor gene does not have to be linked to the rest of the operon.

c. The repressor protein exists in two forms -- one that binds the operator (& blocks transcription) and one that does not bind the operator. (On handout, rectangle vs circle.)

3. Effectors -- Each repressor/regulator protein binds an effector (inducer or co-repressor) -- binding of the effector changes the shape of the repressor protein, so that transcription is either turned on (induction, middle panel) or off (repression, bottom panel).

C. How transcription of cluster is turned off -- Roles of Repressor & Operator. Upper Right Panel of 16B = operon that is "off." See Becker fig. 20-3 (23-3), top panel or Sadava fig. 16.5 top panel.

1. The 2-Part Switch -- There's a two part switch (controlling transcription) of each operon -- it consists of

a. The repressor protein

b. The DNA sequence to which it binds = operator .

2. Role of operator (O).

a. What is it? Operator = DNA site where repressor binds = half of two part switch.

b. There is a different operator for each operon . Each operator consists of a specific DNA sequence that is recognized by the repressor of that operon.

c. Function: Operator binds repressor (regulator) protein when repressor is in appropriate or active form (rectangle on handout). Binding of repressor to its respective operator shuts down transcription.

3. Role of repressor

a. What is it? Repressor = Protein that binds to operator (O) = other half of on/off switch.

b. Function: Binding of repressor protein to an operator prevents RNA polymerase from transcribing the operon. (Purves fig. 13.15 in 7th ed). Binding of repressor either prevents RNA polymerase binding or blocks the enzyme's progression down the DNA.

c. There is a different repressor protein (& operator) for each operon. Repressor binds to specific sequence of DNA found in its respective operator.

Reminder: How can a protein bind specifically to a unique site on the DNA? The side chains of the AAs in a protein can form weak bonds with the bases in a groove of the double helix. A specific DNA sequence can match up with a specific protein because the order of the bases determines both the shape of the groove and the groups available to form weak bonds to the protein side chains.

d. Terminology. The terms 'repressor' and 'repressor protein' are used interchangeably. The term 'repressor' is used in both induction & repression because the job of the protein is to turn the operon off. However some prefer to use the term 'regulator protein' instead of 'repressor protein' when referring to induction.

4. Synthesis of repressor

a. Where does repressor come from? It is encoded by its own gene. (Middle and bottom panel of handout.)

b. Synthesis of repressor protein is constitutive -- gene is always on. (State of repressor protein varies, not the amount; see below.)

c. Where is the repressor gene? The repressor gene does not have to be linked to the rest of the operon.

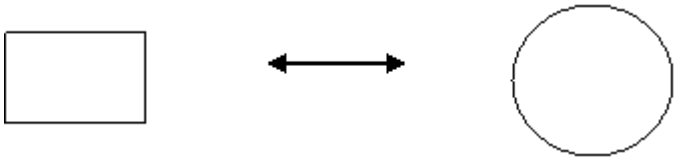
Question: Does the gene for repressor protein have a promoter? an operator?

D. Important Repressor Protein Features

1. Repressor protein is allosteric (has two forms) -- See Becker fig. 20-5 (23-5).

a. Form that sticks to the operator -- active form, represented by a rectangle. Binds to the operator (& blocks transcription)

b. Form that doesn't stick to O -- inactive form, represented by a circle. Does not bind the operator, so transcription can proceed. See Becker Fig. 20-5 (23-5).



2. Role of Effector molecule (inducer or co-repressor) -- binds to one form of repressor protein and shifts above equilibrium to right or to left. Details below.

3. How many different repressor proteins? Many!

a. One repressor per operon. Each operon has its own unique repressor protein (and its own unique operator sequence). Each individual repressor protein has a unique sequence, shape, etc.

b. Each repressor is unique, but all are allosteric – have two forms. The diagrams of circles and rectangles do not mean that all repressors are the same -- the diagrams only mean that each individual repressor has an active and inactive form.

4. Binding sites of repressor protein -- each repressor has two binding sites

a. Site for binding to operator: Each repressor binds to the sequence of double stranded DNA at the operator of 'its' operon. (The different DNA binding sites on different repressors are *not* shown in the pictures below.)

b. Site for binding to effector: Each repressor binds to 'its' effector. (The different effector binding sites on different repressors *are* shown in the pictures below.)

III. Induction vs Repression

See handout 16B, middle and bottom panel. For a more detailed comparison of induction vs repression see section IV-C below.

A. How operons are turned 'on' and 'off' -- Role of Effectors

1. Effector can be an inducer or co-repressor

2. Effector binds to Repressor. Each repressor/regulator protein is unique in that it has a binding site for the proper co-repressor or inducer as well as a binding site for the proper operator.

3. Effector determines which form the repressor is in.

- The amount of repressor protein present doesn't change; the form repressor is in **does** change.
- The small molecule effector (inducer or co-repressor) shifts the balance between the two forms (rectangle and circle = DNA binding form or not) thus shifting the equilibrium above to left or right.
- Shift of equilibrium changes the amount of bound (active rectangle) repressor and free (inactive circle), thus turning the operon "off" or "on."

4. Negative Control.

- Regulatory system is "negative" -- meaning a protein (repressor) must function properly to turn transcription of the system **off**.
- If the repressor protein is missing or does not work, transcription is stuck in the "on" position.

5. Induction vs Repression (Examples of each are below. A thorough comparison of induction & repression, for study purposes, is included below in section IV-C.)

- Induction -- inducer ***prevents*** repressor protein from binding to the operator. (Shifts equilibrium above to right.)
- Repression -- co-repressor ***needed*** to allow repressor protein to bind to the operator. (Shifts equilibrium above to left.)

6. How does repressor get on or off the DNA? (Details are FYI.)

The picture on the handout shows that the repressor is either "on" the operator (in rectangle form) or "off" the operator, (in circle form). There are 2 basic models for how the repressor gets on or off the operator. They are described below, but none of the problems in this course require you to know the difference between the two.

FYI, for those who like the details, below are the two models for how an effector works. Older versions of the notes explained model a, but current evidence favors model b.

a. On/Off model: There is an equilibrium between free and bound "sticky" (rectangle form) repressor -- "rectangular" molecules are spontaneously coming on and off. The effector binds to the free repressor in the cytoplasm (not the repressor bound to the DNA). Binding of repressor and effector shifts the equilibrium between free rectangles and circles, which in turn shifts the equilibrium between free and bound rectangles.

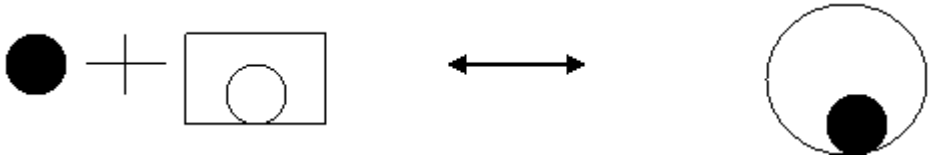
b. Sliding model: The effector binds to the repressor while the repressor is still on the DNA. This changes the repressor's conformation, and causes it to move onto or off the operator. (In this model the repressor is always bound to DNA, but it slides from a random spot -- where it has no effect -- to the operator, or vice versa.)

B. An example of Induction-- *(see middle panel of handout 16B or Becker fig. 20-3 (23-3) or Sadava fig. 16.5. For an animation try http://vcell.ndsu.nodak.edu/animations/lacOperon/index.htm. Additional animations are listed on the links page. (There are multiple animations on the web and on YouTube. If you find an animation that is especially useful, please tell Dr. M.)*

What are the characteristics of an inducible Operon? (diagram on next page)

- **Empty** form of repressor protein (rectangle without effector) sticks to operator.
- Effector molecule (inducer) binds to repressor protein & causes rectangle form to change to circle form.
- Circle form of repressor protein (with effector) falls off the operator.

- Effector (Inducer = small dark sphere) shifts following equilibrium to **right**:



"Rectangle form" of rep. protein ↔ "Circle form" of rep. protein
("sticky" form that binds to O) ↔ (form that doesn't bind to O)

- Result: Effector molecule (inducer) that binds to repressor protein **prevents** repressor from binding to operator

To review regulation so far, try problem 12-0.

C. An example of repression *(see bottom panel of handout 16B or Becker fig. 20-6 (23-6) or text of Sadava (no figure).*

What are the characteristics of repressible Operon?

- **Full** form of repressor protein (rectangle with bound effector) sticks to operator.
- Effector molecule (co-repressor) binds to repressor protein & causes circle form to change to rectangle form.
- Rectangle form of repressor protein (without effector) binds to the operator.
- Effector (co-repressor = small dark triangle) shifts following equilibrium to **right**:

"Circle form" of rep. protein ↔ "Rectangle form" of rep. protein
(form that doesn't bind to O) ↔ ("sticky" form that binds to O)

- Result: Effector molecule (co-repressor) that binds to repressor protein **stimulates** repressor binding to operator

For a more detailed comparison of induction and repression, see below, section IV-C.

IV. Analyzing Operons

A. Constitutive Mutants -- *How can an inducible or repressible operon get stuck in the 'on' position? How will you tell what is mutated?*

1. What happens if repressor protein is mutant and doesn't bind to DNA at all? Will an inducible operon be on? off? What will happen to a repressible operon?

2. What type of mutation? If you want the repressor protein to be totally inactive, which type of mutation (nonsense or mis-sense) would you be likely to aim for?

3. How else to get a constitutive mutant? Suppose the repressor gene is normal. Is there any other way to get a constitutive operon?

See problem 12-3, part A.

4. How do you test out the properties of constitutive mutants?

a. Many experiments and problems involve having a cell with two copies of an operon. *How this is done is explained in detail below.*

b. How is this possible? Bacteria are haploid -- each bacterium normally has only one DNA molecule (chromosome) with one copy of each gene or operon. (See note on terminology at * below.)

c. Bacteria can acquire an extra copy of a gene or an operon; the extra copy is usually on a plasmid. Such cells are called partial diploids.* (How cells acquire plasmids will be discussed next time.)

d. What are plasmids?

(1). Plasmids are mini-chromosomes that can have 'extra' genes. Each plasmid has an origin of replication, so plasmids are replicated and passed on.

(2). The 'extra' genes on the plasmid can be totally new or they can be additional copies of the genes already in the cell (on the chromosome).

(3). A bacterium with a plasmid can be a partial diploid* -- it can have two copies of a gene or two copies of a whole operon. One copy will be its normal place on the chromosome and the other copy will be on a plasmid.

*Terminology: A cell with one copy of every gene is called a haploid; a cell with two copies of every gene is called a diploid. A cell that is basically haploid, but has two copies of a few genes is called a partial diploid.

e. What use are partial diploids? The two copies do not have to be exactly the same -- one can be normal and one mutant, or they can both be different mutants. For example, suppose a bacterium has two copies of the lactose operon. Suppose one copy is constitutive and the other is inducible, or suppose both are constitutive. What should happen when you put the two operons together? Will both be constitutive? Both inducible? (More examples when we get to complementation & recombination.)

(1) Operators (and Promoters) only affect regulation of genes on the same DNA molecule. Therefore these regulatory sites/genes, and mutations in them, are said to act in 'cis.' **

(2) Repressors can affect regulation of genes on other DNA molecules (other than the one that encodes them). Therefore the repressor genes, mutations in them, and the proteins they encode, are said to act in 'trans.' **

**Note: The cis vs trans acting terminology is not used in the problem book, and will not be used on exams, but is explained here because you may encounter it in your reading. It will be re-introduced next term.

To learn how to tell the types of constitutive mutants apart, see problem 12-4 & Becker table 20-2 (23-2).

5. Use of Mutants. Study of the properties of constitutive mutants was how induction & repression were figured out by Jacob and Monod, who received the Nobel prize in 1965 for their work. Now you can try it the other way -- you can use your knowledge of operon function to predict the properties of mutants, both singly and in combination. (See problem set 12.)

B. Role of Promoter vs Operator

1. Overall role of operator vs promoter -- Promoter determines what the maximum level of transcription is; Operator (plus Repressor) determines what percent of maximum is actually reached. Details below in 5.

2. All Promoters are similar in structure and function -- all P's have to able to bind RNA polymerase and serve as signals to start transcription. However, not all promoters are the same.

3. P's can be strong or weak

a. Weak Promoter → little (or infrequent) RNA polymerase binding → low levels of transcription → low levels of corresponding protein.

b. Strong Promoter → lots of (or frequent) RNA polymerase binding → high levels of transcription → high levels of corresponding protein.

c. Why does strength of promoter matter? The strength of the promoter determines how much mRNA can be made (in an individual cell). Actual amount of mRNA made at any time (in total culture) depends on both strength of promoter and extent of repression or induction. (See 4 below.)

4. Example of strong vs. weak Promoters: P of lac operon vs P of lac repressor gene

a. Promoter of lac operon is strong. P of lac operon = P for the structural genes; controls production of polycistronic mRNA → enzymes for metabolism of lactose. Since this P is strong, you make a lot of mRNA and a lot of the corresponding enzymes.

b. Promoter of lac repressor gene is weak. P of lac repressor = P for the R gene; controls production of mRNA for lac repressor → lac repressor protein. Since this P is weak, you make only a little of the mRNA, and relatively little of the repressor protein.

c. Why does this make sense? You need a lot of the metabolic enzymes per cell (if you are growing on lactose as a carbon and energy source) but relatively few molecules per cell (100 or so) of repressor protein.

Note: one molecule of active repressor (in the "rectangle form") per cell is not enough to shut down one operon. There has to be more than one molecule of active repressor protein per operon to be sure the operator in an 'off' operon is always occupied with a repressor protein molecule.

5. How Role of O (operator) differs from role of P (promoter).

a. O (by binding to repressor) determines to what extent transcription (& protein synthesis) is "on" -- is protein synthesis running at full throttle or is it only partially turned on (or completely off)? Each individual operon or cell is probably "off" or "on" at any one moment. However, in an entire bacterial culture, not all cells are necessarily on or off. At intermediate levels of inducer, some cells may have their operon turned on and some may not. In these cells, some of the repressor protein is in the "rectangle" or active form, and some is in the "circle" or inactive form. There is some variation from cell to cell, and there is a threshold value for the amount of active repressor required to keep the operon 'off.'

b. P determines the maximum level of transcription = level per culture when all operons are "on" and running at full throttle = level per cell when culture is fully induced.

c. Relative positions of P and O. In all our pictures, the operator is between the promoter and the structural genes. This is not always the case -- the relative positions of P and O are variable. (The repressor protein is very large, and can overlap the promoter in either case.)

See problem 12-3, and compare parts A & B.

C. Induction vs. Repression -- Detailed Comparison

Much of the material below is a review of the material in previous sections, and will not be repeated in class. However, it is repeated here so you can use the questions (1) to (3) below to distinguish inducible and repressible operons.

1. What features of repressible and inducible operons should be compared? Consider the following questions:

(1) Which form of the repressor protein, empty or full, sticks to the DNA?

(2) When repressor protein is made, is it 'sticky'?

(3) How (in which direction) does the effector shift the equilibrium between sticky and non-sticky forms?

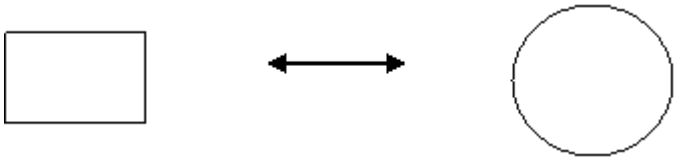
2. What are the characteristics of an Operon (either type)?

a. Role of Repressor protein -- binds to operator and shuts off transcription of operon|

b. Repressor protein has two forms. (See Becker fig. 20-5 (23-5)).

(1). "Rectangle form" of rep. protein = "sticky" form that binds to Operator

(2). "Circle form" = form that doesn't bind to Operator



c. Role of Effector molecule (inducer or co-repressor) -- binds to one form of repressor protein and shifts above equilibrium to right or to left.

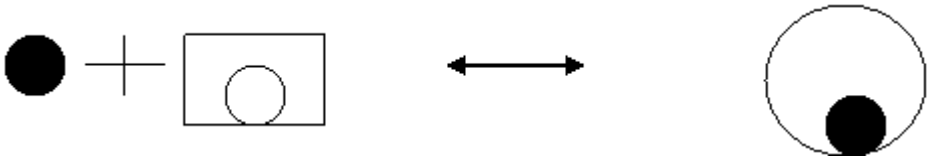
3. What are the characteristics of an Inducible Operon? (See Becker fig. 20-3 (23-3) or Sadava fig. 16.5.

a. Overall: Effector molecule (inducer) that binds to repressor protein **prevents** repressor from binding to operator -- decreases supply of rectangles by converting them to circles.

b. What binds to DNA? Empty form of repressor protein (without effector) = rectangle; sticks to operator

c. Role of Effector (Inducer): shifts reaction below to **right**.

effector + Rectangle form (empty) ↔ Circle form (full)



d. Inducer symbol: On handout, inducer = small dark sphere

4. What are the characteristics of a Repressible Operon? (See Becker fig. 20-6 (23-6) or Sadava text.

a. Overall: Effector molecule (co-repressor) that binds to repressor protein **promotes** repressor binding to operator -- increases supply of rectangles by converting circles to rectangles.

b. What binds to DNA? Full form of repressor protein (effector-protein complex) = rectangle; sticks to operator.

c. Role of Effector (co-repressor): shifts reaction below to **left**.

Rectangle form (full) ↔ Circle form (empty) + effector

d. Co-repressor symbol: On handout, co-repressor = small dark triangle

e. To compare to induction, can also write the reaction:

Circle form (empty) + effector ↔ rectangle form (full)

Effector shifts equilibrium of reaction (written as in e) to the **right.**

For an animation of repression (the trp operon) go to http://highered.mcgraw-hill.com/olc/dl/120080/bio26.swf

5. Reminder:

a. The repressor protein of each operon is unique, and binds only to its respective operator (& effector).

b. Not all rectangles (or circles) are the same.

(1). Each unique repressor protein is allosteric and has 2 forms -- "sticky" and "nonsticky."

(2). For comparison, on the handouts, all "sticky" forms are drawn as rectangles and all "nonsticky" forms are drawn as circles.

(3). However, each repressor protein is different. The only thing all "rectangles" have in common is that they all stick to their respective operators.

Before attempting the problems, it might help to make a table for yourself comparing induction & repression -- make a table with the answers to the questions at the start of this section. To review how operons work, do problems 12-0, 12-1 and 12-2 A-B. To compare repression and induction, do 12-2 C, and 12-7. To review the differences between repression and feedback inhibition, try problem 12-2, esp. part D, and 12R-4.

V. Regulation of Gene Expression In General

This section will not be discussed in class but is included to help you get the big picture. It will be discussed in detail next term when we get to regulation of eukaryotic protein synthesis.

1. All models of regulation are based on knowledge of operons. Why? Because operons were the first systems of regulation of protein synthesis to be understood.

2. Features of operons to consider -- see above

a. Transcriptional Control.
b. The 2-Part Switch.
c. Negative Control.
d. Co-ordinate Control.

3. Are these features universal? Does Regulation of protein synthesis always work the same way? Is what is true of *E. coli* true of the elephant? (Monod, one of the originators of the operon model, liked to think so.)

a. Transcriptional control is common. It is the primary way, but not the only way, to regulate protein synthesis. In eukaryotes, other steps are often controlled as well.

b. Two part switches, consisting of a protein and DNA site are very, very common. The situation is often more complex than the one described above, especially in eukaryotes. For example: Either half of the switch can be made of RNA. Often there are multiple sites and/or multiple regulatory proteins (which can interact with each other as well as with DNA) that can affect transcription of a particular gene. Details will be discussed next term.

c. Negative control is not universal. Negative control is very common in prokaryotes; positive control (where a protein is needed to turn ON a gene) is more common in multicellular eukaryotes.

d. Co-ordinate control is common, but the mechanism is different in different organisms. Genes of related function are generally clustered in prokaryotes, and share a common "switch (P, O etc.)." Genes that code for multiple enzymes of the same pathway are generally NOT clustered in eukaryotes. Since each gene in the set is located in a different place, each gene has its own "switch." (But all the switches are tripped coordinately.) So there is generally no polycistronic mRNA in multicellular eukaryotes.

The remaining material will probably be in Lecture #18

VI. How is bacterial DNA passed on? Asexual Reproduction

A. Introduction to cell division -- How does 1 cell make 2?

1. How do you double cell contents? Consider the central dogma -- we've covered it all -- how to double DNA, RNA and protein, and how to regulate protein synthesis. Once you double the protein (enzymes),that allows doubling of everything else, like carbos, lipids, etc. So suppose you double everything in the cell. How do you get 2 cells from 1?

2. Why distribution of DNA is the critical issue -- Making two cells from one comes down to "once the program is doubled, how are the two copies distributed to daughter cells?" Stuff that is not part of the program (not part of the genetic material) need not be divided exactly, but because of the chicken and egg problem, there must be **some** of the other material in each daughter cell. (Need some ribosomes, RNA polymerase etc. in each cell. But as long as you have some, and the genetic material, you can always make more ribosomes, enzymes etc.)

B. How do prokaryotes do it? binary fission -- regular segregation of circular chromosome attached to membrane

1. What does the DNA (genetic information) of a bacterium look like? Each bacterium has one, circular, double stranded DNA molecule = chromosome; the chromosome is attached to the cell membrane.

2. How the Chromosomal DNA is distributed.

a. To start, you have one cell with one double stranded DNA circle attached to membrane.

b. DNA replicates by birectional DNA replication (two forks start from a single origin) → two double stranded circles, both attached to membrane. (See Becker fig. 17-6 (19-4))

c. Circles grow apart as membrane is laid down between the attachment points of DNA to membrane → two circles pushed to opposite ends of cell. (There is also an active process, other than growth of membrane, that pushes the two origins of DNA replication apart. This has only been recently discovered.)

d. To end, you need only to lay down a membrane (and wall) between the two halves of cell, each containing one circle (= complete double stranded chromosome). This → 2 complete cells.

e. Note this is not mitosis OR meiosis; it is a different process (binary fission). Mitosis and meiosis occur only in eukaryotes; they will be discussed later.

f. How will the genetic material in the two daughter cells compare? If there are no mutations it will be the same, and all descendants will be identical. All the descendants produced in this way (by asexual reproduction of a single founder) are called a clone. (Doesn't matter if "founder" is a cell, molecule, or organism.) Is there any way (besides mutation) to get new combinations of genes? To mix genes from separate clones? That requires bacterial sex.

VII. Introduction to Bacterial Sex

A. What is the biological definition of sex? Any method for exchanging genes and/or passing DNA around from organism to organism. Mutation produces variants; sexual reproduction (re)shuffles them and produces new combinations.

B. Haploid & Diploid -- Terminology Reminder

1. Haploid = A cell (or organism) with one copy of each chromosome/DNA molecule. Therefore one copy of each gene. Example: bacteria.

2. Diploid = A cell (or organism) with two copies of each chromosome (usually one copy from each parent). Therefore 2 copies of each gene. Examples: mammals, higher plants & animals.

3. Partial Diploid = A cell (or organism) that is basically haploid, but has two copies of a few genes. This can happen in nature, or as a result of lab manipulations. How are extra copies acquired and passed on? See below.

C. How do bacteria get 'extra' DNA? *Three basic ways to be explained in greater detail next time:*

1. DNA Transformation -- DNA released from one bacterium is taken up by another.**

2. Conjugation -- DNA is passed by cell-cell contact (mating -- forming a bridge).

3. Viral Transduction -- DNA is carried by a virus from one host to the next.

**Note: DNA transfer from cell to cell in eukaryotes is not usually called 'transformation' because the term 'transformation' is used instead to refer to cancerous transformation -- the transformation of a normal cell into a cancer cell. When speaking of DNA transfer in eukaryotes, the term 'transfection' is usually used instead of the term 'transformation'. (How the DNA is passed from one eukaryotic cell to another will be discussed later in the term. It does not necessarily involve viruses.)

For pictures, see Sadava fig. 12.21 & 12.22 (12.23 & 12.24) or Becker 25-18 to 25-20 (20-18 to 20-20).