STUDY GUIDE - Ch. 15.3 - Linked Genes Tend to be Inherited Together Because They are Located Near Each Other on the SAME Chromosome NAME: ______________________

- **PHYSICALLY PRINT OUT this PDF and HANDWRITE (with a black or blue pen) your answers directly on this PDF.** *Typed or digitally-written work is **not** accepted. Do **not** answer questions on separate paper.*
- **Importantly, study guides are NOT GROUP PROJECTS!!!** *You, and you alone, are to answer the questions as you **read** your assigned textbook. You are **not** to share answers with other students. You are **not** to copy any answers from any other source, including the internet.*
- **Get in the habit of writing LEGIBLY, neatly, and in a medium-sized font.** *AP essay readers and I will skip grading anything that cannot be easily read so start perfecting your handwriting, and don't write so large you can't add all the relevant details and key elaborations in the space provided.*
- **SCAN physical documents in color and with good resolution. Then, upload your final work as PDFs to Archie.** *Avoid uploading dark, shaded, washed-out, sideways, or upside-down scans of homework. Keep completed physical study guides organized in your biology binder to use as future study and review tools.*
- **READ FOR UNDERSTANDING and not merely to complete an assignment.** ***First**, read a section quickly to get an overview of the topic covered. Then, read it a **second** time slowly, paraphrasing each paragraph **out loud** and analyzing every figure. Finally, read it a **third** time as you answer the study guide questions if assigned and start building your memory. Try to write answers out in your own words, when possible, and try to purposefully and accurately use all new terminology introduced.*

1. What does it mean when genes are **linked** (or exhibit **linkage**)?

2. **Study carefully each step of the Figure 15.9 inquiry.** Notice the **predicted ratios** if the 2 genes were located on **different** chromosomes versus if the 2 genes are located on the **same** chromosome (& CROSSING OVER IN THE FEMALE HETEROZYGOTE DOES **NOT** OCCUR). **Understand why the ratios differ in these two scenarios!**

   The P generation female, which made the F1 heterozygous female, was diploid and a true breeder $b^+ b^+ vg^+ vg^+$ while the male pure breeder in the P generation had genotype b b vg vg. Each of these two parents gave one copy of each gene to their F1 female offspring since each parent gives one set of chromosomes to their offspring.

   a. Had these two genes genes **not been linked**, the gene for body color and the gene for wing color would have been located on two **different** types of chromosomes. Had this been the case, draw, in the cell below, the **two** tetrads that would be present at **Metaphase 1** in the female F1 fly with genotype $b^+ b\ vg^+ vg$ during meiosis. Label all **eight** of the chromatids with the correct alleles for the genes and make it clear that the chromosomes in your two tetrads are different by drawing chromosomes of two clearly **different** sizes. **You should see that these two genes (and their alleles) would be able to sort independently during Metaphase 1 of Meiosis I.**

   F_1 $b^+ b\ vg^+ vg$ Hybrid at Metaphase 1
   (two genes not linked)

   ♀

   Hint: Think first of what the chromosomes in a eukaryotic, diploid (2n) nucleus would look like when unduplicated in G_1. Then think of what happens during S phase, before G_2 occurs and M phase stats. ***(Ch.13)***

   b. If the genes were not linked and sorted independently, what would have been the **genotypes of the possible gametes** (reproductive cells) the female **$b^+ b\ vg^+ vg$** F1 fly could make? *Remember, gametes are haploid (n), not diploid (2n), contributing one set of chromosomes and thus one set of each of the genes.*

   1. ____________ **2.** ____________ **3.** ____________ **4.** ____________

   c. Draw the chromosomes as they would appear in the nucleus of each possible female **$b^+ b\ vg^+ vg$** F1 gamete. Remember, the chromosomes would now be in G1 and no longer be duplicated. **Label the alleles on the DNA.**

   1. **2.** **3.** **4.**

d. If the genes were not linked and sorted independently, what would have been the **genotypes of the possible gametes** (reproductive cells) the male **b b vg vg** F1 fly could make? *Remember, gametes are haploid (n), not diploid (2n), continuing one set of chromosomes and thus one set of each of the genes on these chromosomes.*

1. ____________ **2.** ____________ **3.** ____________ **4.** ____________

e. Draw the chromosomes as they would appear in the nucleus of each possible male **b b vg vg** F1 gamete. Remember, the chromosomes would now be in G1 and no longer be duplicated. **Label the alleles on the DNA.**

1. **2.** **3.** **4.**

f. Draw **ONE dihybrid Punnett Square** showing the offspring that could be produced when mating the female and male from 2.b and 2.d = **b^+ b vg^+ vg x b b vg vg** *(Make your punnet squares large and neat)*.

g. Based on your Punnett Square above, what was the **phenotype ratio Morgan predicted/expected in the F2 generation if the genes for wing shape and body color were NOT linked** and sorted independently *(the two genes were found on two **DIFFERENT** types of chromosomes)*?

To his surprise, when Morgan performed this cross, b^+ b vg^+ vg x b b vg vg, he did NOT get the predicted results in the F2 generation.

h. Morgan thus concluded that these two genes (for body color and for wing color) were instead **linked so they do NOT assort independently during Meiosis**. They were located on the **SAME** chromosome! Let's see how these two genes behave differently when linked (instead of when sorting independently).

Remember that Morgan made the F1 heterozygous female by mating a P generation female that was diploid and a true breeder b^+ b^+ vg^+ vg^+ with a P generation male pure breeder that had genotype b b vg vg. Draw what the **unduplicated chromosome** carrying these two linked genes would look like during **G1 in the P generation diploid (2n) female and P generation diploid (2n) male**.

P generation true breeding female in G_1
b^+ b^+ vg^+ vg^+
(two genes linked)

♀

P generation true breeding male in G_1
b b vg vg
(two genes linked)

♂

i. Draw what the chromosomes in the G1 nucleus would look like in the diploid (2n) F1 generation female that would be produced by the mating of the true breeders ($b^+ b^+ vg^+ vg^+$ x $b\ b\ vg\ vg$) in 2.h. above.

F_1 generation hybrid female in G_1
$b^+ b\ vg^+ vg$
(two genes linked)

♀

j. Draw the single **tetrad** that would form during Prophase 1 and, thus, be present in **Metaphase 1** in the **female F1 fly with genotype $b^+ b\ vg^+ vg$ and the genes linked**. Label **all** four of the chromatids with the correct alleles for the genes.

F_1 $b^+ b\ vg^+ vg$ Hybrid at Metaphase 1
(two genes linked)

♀

Hint: Instead of two pairs of different homologous duplicated chromosomes as you should have drawn in 2.a, you should now only show one pair of homolous duplicated chromsomes.

k. If the genes are linked and do NOT sorted independently, and **assuming for now that NO CROSSING OVER OCCURS**, what would be the **genotypes of the possible gametes** (reproductive cells) the female **$b^+ b\ vg^+ vg$** F1 fly would make based on your drawing in 2.j.? *Remember, gametes are haploid (n), not diploid (2n), contributing one set of chromosomes and thus one set of each of the genes.*

1. ____________ **2.** ____________ **3.** ____________ **4.** ____________

l. Draw the chromosomes as they would appear in the nucleus of each possible female **$b^+ b\ vg^+ vg$** F1 gamete. Remember, the chromosomes would now be in G1 and no longer be duplicated. **Label the alleles on the DNA.**

1. **2.** **3.** **4.**

m. If the genes were linked and did NOT sorted independently, what would have been the **genotypes of the possible gametes** (reproductive cells) the male **b b vg vg** F1 fly could make? *Remember, gametes are haploid (n), not diploid (2n), contributing one set of chromosomes and thus one set of each of the genes.*

1. ____________ **2.** ____________ **3.** ____________ **4.** ____________

n. Draw the chromosomes as they would appear in the nucleus of each possible male **b b vg vg** F1 gamete. Remember, the chromosomes would now be in G1 and no longer be duplicated. **Label the alleles on the DNA.**

1. **2.** **3.** **4.**

o. Draw **ONE** Punnett Square showing the offspring that would be produced when mating the female and male from 2.k and 2.m, **b^+ b vg^+ vg x b b vg vg**, when the genes for wing shape and body color are **linked** and if **NO CROSSING OVER OCCURS DURING MEIOSIS**. *(Make your punnet squares large and neat).*

g. Based on your Punnett Square above, what is the **phenotype ratio you would expect in the F2 generation if the genes for wing shape and body color are linked** *(the two genes are found on the same type of chromosomes)* and no crossing over occurs during Prophase 1 of Meiosis when the gametes are produced?

As you can see in Figure 15.9, most of Morgans F1 flies in this **test cross** between a female heterozygous for both wing shape and body color and a male homozygous mutant for wing shape and body color looked like the **Parental Phenotypes** **(= the phenotype trait combinations of the P GENERATION flies!!!)**, being either gray with normal wings or black with vestigial wings. Given that he did **not** get the 1 gray body normal wing : 1 gray body vestigial wing : 1 black body normal wing : 1 black body vestigial wing ratio expected when these two genes sort independently, most F2 flies looking instead more like the P generation phenotypes either gray body normal wing or black body vestigial wing, he concluded that the genes are linked and on the same type of chromosome.

Curiously, a small number of F2 flies *(way less than would be expected if genes sort independently and were found on different chromosomes)* **did have non-parental phenotypes that looked different from the starting P generation flies being gray but with vestigial wings or black but with normal wings.** Morgan, thus, concluded that there must of been some mechanism that sometimes breaks the linkage between the specific alleles of two genes located together on the same chromosome. Today, we know the mechanism is **crossing over,** occurring during Prophase 1 in Meiosis 1.

3. What are the **three ways sexual reproduction (using meiosis) generates genetic variation** among offspring?

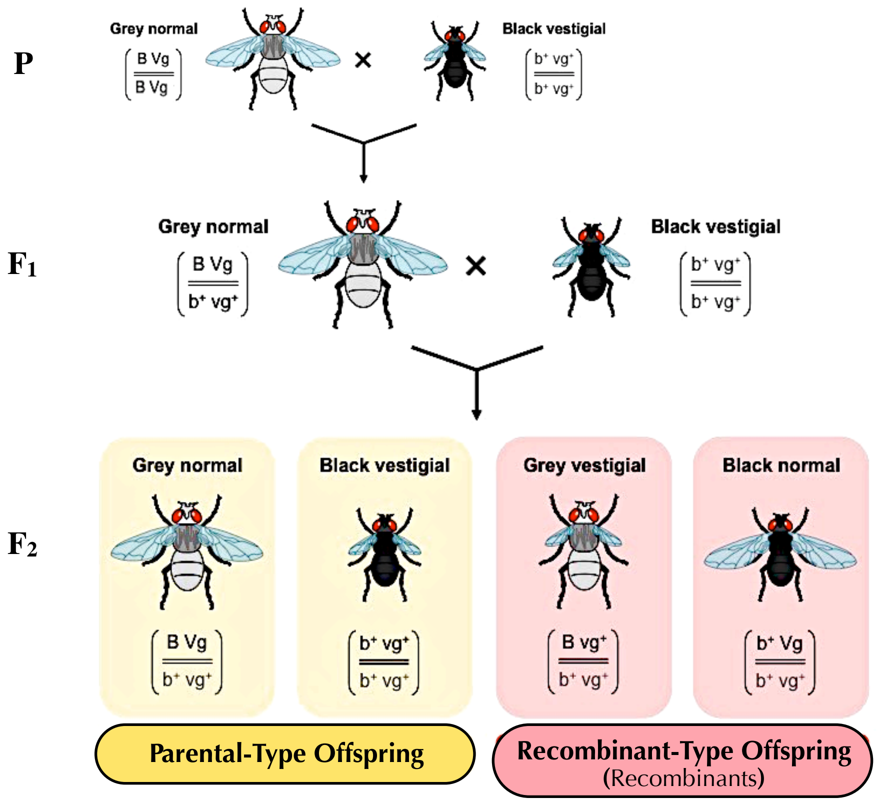
   1.

   2.

   3.

4. As you read, the word recombinant is critical to understand. **Recombinants are F1 or F2 offspring that have new phenotypes that differs from those of the P generation.** The allelic combination of different genes have been altered in the recombinant compared to the allelic combination in the genes of the P generation parents. In the example with peas in your textbook, **recombinant offspring** of a round and yellow seed heterozygous parent (which had P generation parents with round and yellow seeds and with wrinkled and green seeds) crossed with a green and wrinkled seed homozygous recessive parents would have yellow and wrinkled seeds **OR** green and

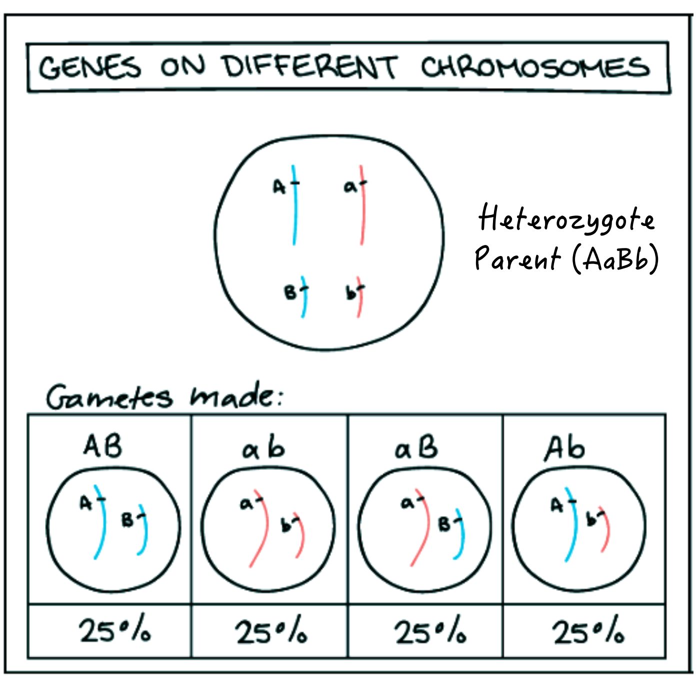
round seeds. Offspring that have round and yellow seeds or green and wrinkled seeds are **NOT** recombinants and are referred to as **parental types**, not recombinant types. Morgan also saw parental versus recombinant flies appear in his F2 flies, some of which did not have the gray body and normal wings or the black body and vestigial wings that the initial P generation flies had, which were mated to make the F1 female flies that later were used to produce these F2 generation flies.



a. Assume we are conducting a test cross in which we cross a heterozygote for **two UNLINKED genes (AaBb)** with a homozygote for these genes **(aabb)**. The homozygote can only make one type of gamete **(ab)** unlike the heterozygote. The heterozygote can make gametes that pass along the **parental phenotype information** **(AB like parent #1 and ab like parent #2).** The heterozygote can also though make gametes that pass along the **non-parental phenotype information** **(Ab and aB).**

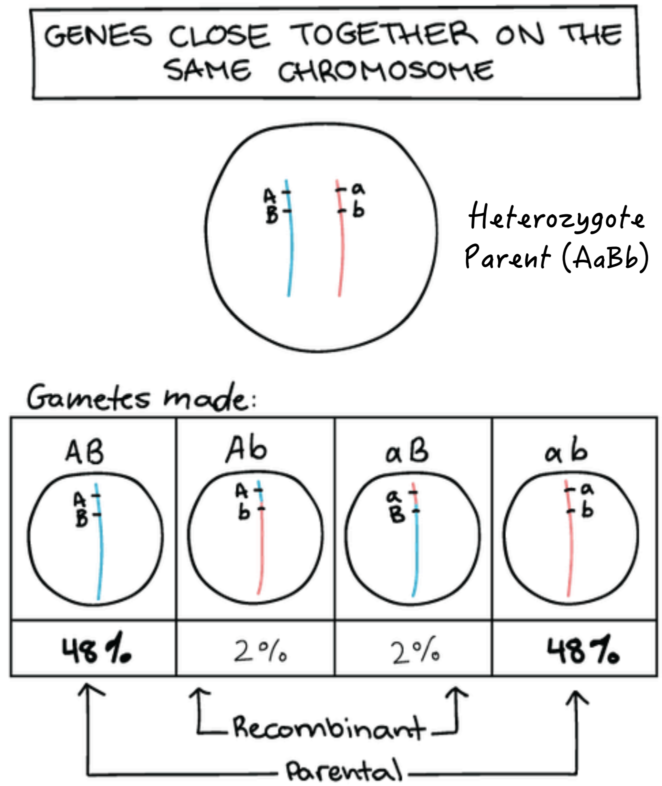
What **stage of meiosis** in the heterozygote is responsible for making recombinant gametes (is responsible for the physical recombination between alleles of unlinked genes), which will lead to the the creation of recombinant offspring?

What would be the **frequency of recombination between two genes located on two different chromosomes**? Meaning what is the chance that instead of **A** sorting into a gamete with **B** and **a** sorting into a gamete with **b**, **A** sorts into a gamete with **b** while **a** sorts into a gamete with **B** instead?



b. Now lets assume we are conducting a test cross in which we cross a heterozygote **(AaBb)** for two **LINKED** genes with a homozygote for both linked genes **(aabb)**. The homozygote can only make one type of gamete **(ab)** again (because it only has one type of allele for each type of gene) unlike the heterozygote.

What **process in the heterozygote is responsible** in this scenario **for making recombinant gametes**, which will lead to the creation of recombinant offspring (is responsible for the physical recombination between alleles of linked genes)? *Be sure to name and **describe** what occurs during this process **(Return to Ch.13 to check the answer)***



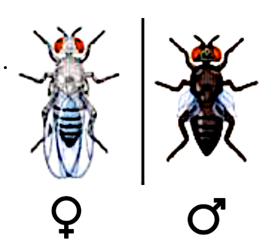
During what exact **stage of Meiosis** does this process described above take place in?

By the way, the two linked genes shown in the figure above exhibit a **4% frequency of recombination**, which means we expect to also see 4% of the offspring between the mating **AaBb x aabb** to be **Recombinants** **(Aabb and aaBb)** and 96% to be **parental types** **(AaBb and aabb)**.

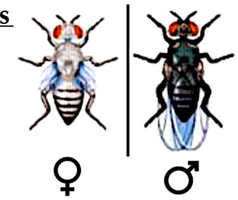
5. Study carefully Figure 15.10, which now shows you the allele locations for the two linked genes (body color and wing shape) present in the fruit flies Morgan crossed in Figure 15.9. Study carefully each step of the figure and each chromosome drawn, making sure to notice the eggs (gametes) the heterozygous female can make **without and with crossing over changing the allelic combination of the two genes on her pair of homologous chromosomes**.

   When you fully understand what is happening during meiosis and gamete formation, and how the chances of making different types of gametes influences the chances of seeing **F2 offspring** that either **DO** look phenotypically like the original **P generation** flies or F2 offspring that **NOT** look phenotypically like the original **P generation** flies, write down neatly and big, the **generic formula** you would use in order to **calculate the frequency of recombination between any two linked genes in a test cross**.

6. Now, let's see if you fully understood the linked genes and their frequency of recombination. Carefully analyze the chromosomes once again in the P, F1, and F2 generation shown in Figure 15.10. In the cross Morgan conducted, the **P generation** flies (which made the F1 heterozygous female) were true breeders for gray body with normal wings (female) and black body with vestigial wings (male). **The gene for body color and wing shape are linked.**



What if the **P generation** flies were instead true breeders for **gray body but with vestigial wings** (female) and **black body but with normal wings** (male). ========================>



a. What are the genotypes for this **P generation** female fruit fly and male fruit fly using Morgan's system of wild type and mutant allele notation. Remember, the vestigial wings and black body mutant alleles behave recessively compared the wile type gray body and normal-shaped wing alleles.

Female Genotype = ________________ **Male Genotype** = ________________

b. Looking at somatic cells that are in G1 of these P generation flies, draw the unduplicated chromosomes in the true breeding female and the true breeding male. Be sure to label the alleles for each gene on both homologs. **DRAW YOUR CHROMOSOMES LARGE AND LABEL THEM CLEARLY.**

G1 Cell of Female P Generation Fly ♀

G1 Cell of Male P Generation Fly ♂

c. As true breeders, both P generation can me only one type of gamete. List the genotype of the female and male P generation gametes and draw the labeled, unduplicated chromosome that each gametes will contain.

Gamete The Female P Generation Fly Produces

Gamete Genotype = ________
(two genes linked)

Gamete The Male P Generation Fly Produces

Gamete Genotype = ________
(two genes linked)

d. If the two P generation flies, whose gametes you drew above mated, draw below the unduplicated G1 chromosomes that would be present in their F1 daughter. **(Remember, the body color and wing shape genes are NOT sex-linked though they are linked. Recall that the wild type allele is dominant to the mutant allele)**

G1 Cell of Female F1 Generation Fly ♀

e. What would be the **female F1 fly's genotype**?

f. What would be the **female F1 fly's phenotype**?

g. Assume a cell in the gonads of the F1 female in 6.d is undergoing meiosis. **This heterozygous F1 female will be test crossed with a male that is a true breeder for black body and normal wings (just like the male in the P generation you drew in 6.a.).** Draw the chromosomes in each of the four possible kinds of eggs this F1 female could produce, making sure to label the alleles on the chromosomes properly **AND**, below each egg, circle YES or NO to indicate if the egg contains chromosomes that are the **non-recombinant versus recombinant**. **Remember, gametes are haploid and contain unduplicated chromosomes, and recombinant chromosomes are those underwent crossing over during Meiosis I!**

♂

Possible Gametes The Female F1 Generation Fly Can Produce (assuming crossing over will sometimes occur)

♀

Recombinant Chromosome?	Recombinant Chromosome?	Recombinant Chromosome?	Recombinant Chromosome?
Yes or **No**	**Yes** or **No**	**Yes** or **No**	**Yes** or **No**

*(Check your answer by going to the Ch.15 **Figure Questions** for **Figure 15.10** in Appendix A of your textbook)*

h. Assuming the female in 6.d. is mated in a **test cross with a true breeding male homozygous for both genes** (black body and normal wing). Draw the chromosome in the one kind of sperm this male could produce. Be sure again to always label the alleles of the genes on the chromosome.

Possible Gamete The Male F1 Generation Fly Can Produce

♂

i. The F1 female (whose gametes you drew in 6.g.) mates with the F1 male (whose gamete you drew in 6.h). Draw the four possible **F2 zygotes (offspring)** this pair can produce **AND**, below each zygote, state whether the offspring will will be a **parental type or a recombinant type** ***(remember you are to compare the F2 phenotypes to the P generation phenotypes, not the F1 phenotypes)***. Be sure again to label the alleles on each chromosome as well, the homolog obtained from the mother and the homolog obtained from the father. Chromosomes in the possible zygotes should all be unduplicated since the gametes that made them had unduplicated chromosomes.

Possible Zygote #1	**Possible Zygote #2**	**Possible Zygote #3**	**Possible Zygote #4**
________________ **Type**	________________ **Type**	________________ **Type**	________________ **Type**

j. Assume that this F1 couple has 3,200 offspring. Of all the offspring, **552 are recombinants** with either black bodies and vestigial wings or gray bodies and normal wings (unlike either of the two P generation flies that had gray bodies but vestigial wings and black bodies but normal wings) and 2,648 are parental types with either gray bodies and vestigial wings or black bodies and normal wings (just like the two P generation grandparents). Using the formula you wrote out in question 5, showing how you plug in all numbers into the formula, calculate the **recombination frequency** of these two genes for body color and wing shape. *(The value you get should match the recombination frequency between the wing shape and body color gene Morgan also got* ***- see Figure 5.10)***

7. Does **natural selection**, which Darwin described as being the mechanism that caused evolution, act directly upon an organism's **phenotype or genotype**? Explain.

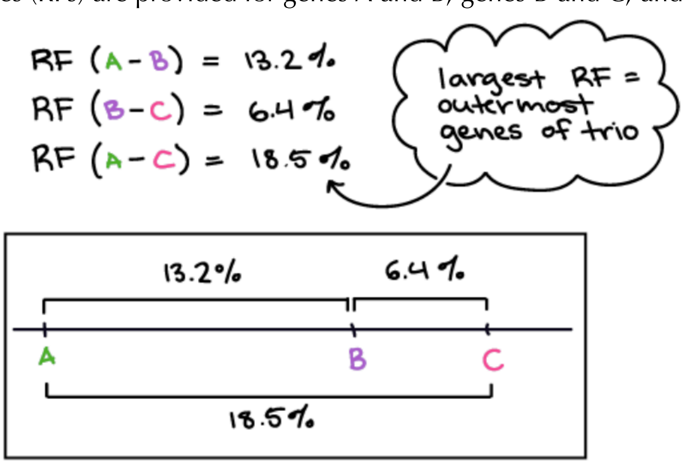
8. a. What is a **genetic map**?

   b. What is a **linkage map**?

   c. Linkage maps express relative distances between genes in terms of map units. What is a **map unit** *(also known as a cM or a centi-Morgan)*? (**Note:** centi-Morgan = Map Units = Recombination Frequency)

9. Sturtevant, hypothesized that the recombination frequency depended on the distance between two genes on a chromosome. He predicted that the ____________________ two genes are, the ____________________ the probability that a crossover will occur between them and, therefore, the ____________________ their recombination frequency.

10. **Read through Figure 15.11. TIP: When drawing linkage maps keep your drawing simple, large, and cleanly labeled.** Draw the **chromosome as a solid horizontal line** and the use short vertical intersecting lines to indicate the relative location of the genes. Be sure to **label each gene location** and to always **include the map unit distances between the genes** on your linkage maps. Follow the same system as is used in the example below in which recombination frequencies (RFs) are provided for genes A and B, genes B and C, and genes A and C.



Once you feel you understand how to construct a linkage map, try the following problem. Genes A, B, and C are located on the same chromosome. Test crosses show that the recombination frequency between A and B is 28% (or 28 cM or map units and between A and C is 12% (or 12 cM or map units). **Always indicate the units of any qualitative value, recombination frequency units being <u>% of recombination</u>, <u>cM</u> for centi-Morgan , or <u>map units</u>)**
As you should quickly realize, you cannot determine the exact linkage map given the information provided alone. You should, however, be able to narrow the linkage map down to two possibilities. Draw the two possibilities below.

<u>Linkage Map Possibility #1</u>	**<u>Linkage Map Possibility #2</u>**

Why can you not determine the exact liner order of these genes? (Check your answer by going to the **Ch.15.3 Concept Check Question #3** answer in Appendix A)

11. a. If you do not know the location of two genes for two different characters, what can you tell about their location if they have a **<u>recombination frequency below 50%</u>**?

b. Why can't you tell if two genes are linked (are on the <u>same</u> type of chromosome) or are unlinked (and thus sort independently) if they have a **<u>recombination frequency of 50% or higher</u>**? Use the two figures showing gamete formation when genes a and b are <u>unlinked</u> versus linked, but over 50 map units apart, to **<u>explain</u>**.