GENETIC LINKAGE

- When genes are found on different chromosomes or far apart on the same chromosome, they assort independently and are said to be **unlinked**.
- When genes are close together on the same chromosome, they are said to be **linked**. That means the alleles, or gene versions, already together on one chromosome will be inherited as a unit more frequently than not.
- We can see if two genes are linked, and how tightly, by using data from genetic crosses to calculate the **recombination frequency**.
- By finding recombination frequencies for many gene pairs, we can make **linkage maps** that show the order and relative distances of the genes on the chromosome.

Linkage is the phenomenon of certain genes staying together during inheritance through generations without any change or separation due to their being present on the same chromosome. Linkage was first suggested by Sutton and Boveri (1902-1903) when they propounded the famous “chromosomal theory of inheritance.”

It was Morgan (1910) who clearly proved and defined linkage on the basis of his breeding experiments in fruitfully Drosophila melanogaster. In 1911, Morgan and Castle proposed chromosome theory of linkage. It states that

(i) Linked genes occur in the same chromosome.

(ii) They lie in a linear sequence in the chromosome.

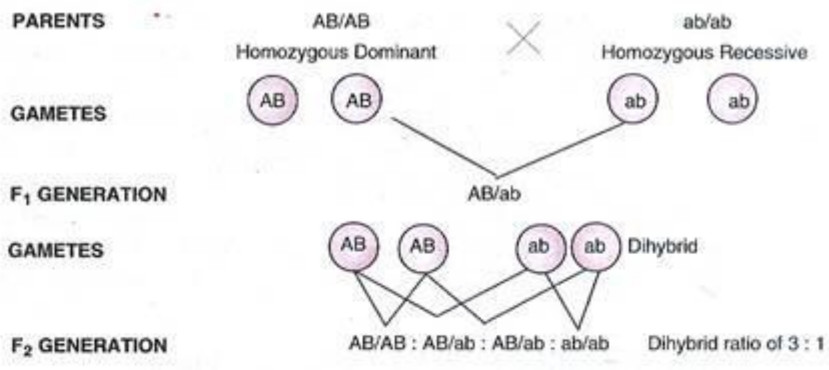
(iii) There is a tendency to maintain the parental combination of genes except for occasional crossovers.

(iv) Strength of the linkage between two genes is inversely proportional to the distance between the two, i.e., two linked genes show higher frequency of crossing over if the distance between them is higher and lower frequency if the distance is small.

Linked and unlinked genes can be easily known from breeding experiments. Unlinked genes show independent assortment, a di-hybrid ratio of 9: 3: 3: 1 and the di-hybrid or double test cross ratio of 1: 1: 1: 1 with two parental and two recombinant types.

The linked genes do not show independent assortment but remain together and are inherited en block producing only parental type of progeny. They give a di-hybrid ratio of 3: 1 and a test cross ratio of 1: 1.

Di-hybrid ratio of two Linked genes



Types of Linkage:

Linkage is of two types, complete and incomplete.

1. Complete Linkage (Morgan, 1919):

The genes located on the same chromosome do not separate and are inherited together over the generations due to the absence of crossing over. Complete linkage allows the combination of parental traits to be inherited as such. It is rare but has been reported in male Drosophila and some other heterogametic organisms.

For example in Drosophila, genes of grey body and long wings are dominant over black body and vestigial (short) wings. If pure breeding grey bodied long winged Drosophila (GL/ GL) flies are crossed with black bodied vestigial winged flies (gl/gl), the F_2 shows a 3 : 1 ratio of parental phenotypes (3 grey body long winged and one black body vestigial winged).

This is explained by assuming that genes of body colour and wing length are found on the same chromosome and are completely linked.

2. Incomplete Linkage:

Genes present in the same chromosome have a tendency to separate due to crossing over and hence produce recombinant progeny besides the parental type. The number of recombinant individuals is usually less than the number expected in independent assortment. In independent assortment all the four types (two parental types and two recombinant types) are each 25%. In case of linkage, each of the two parental types is more than 25% while each of the recombinant types is less than 25%.

Example In Sweet Pea (Lathyrus odoratus) blue flower colour (B) is dominant over red flower colour (b) while the trait of long pollen (L) is dominant over round pollen (1). A Sweet Pea plant heterozygous for both blue flower colour and long pollen (BbLl) was crossed with double recessive red flowered plant with round pollen (bbll). In the above cross Bateson and Punnett (1906) found both parental and recombinant types but with different frequencies in the ratio of 7: 1: 1: 7. (7 + 7 Parental and 1 + 1 recombinant types) showing incomplete linkage.

Linkage Groups:

A linkage group is a linearly arranged group of linked genes which are normally inherited together except for crossing over.

It corresponds to a chromosome which bears a linear sequence of genes linked and inherited together. Because the two homologous chromosomes possess either similar or allelic genes on the same loci, they constitute the same linkage group. Therefore, the number of linkage groups present in an individual corresponds to number of chromosomes in its one genome (all the chromosomes if haploid or homologous pairs if diploid). It is known as principle of limitation of linkage groups.

The size of the linkage group depends upon the size of chromosome. The smaller chromosome will naturally have smaller linkage group while a longer one has longer linkage group.

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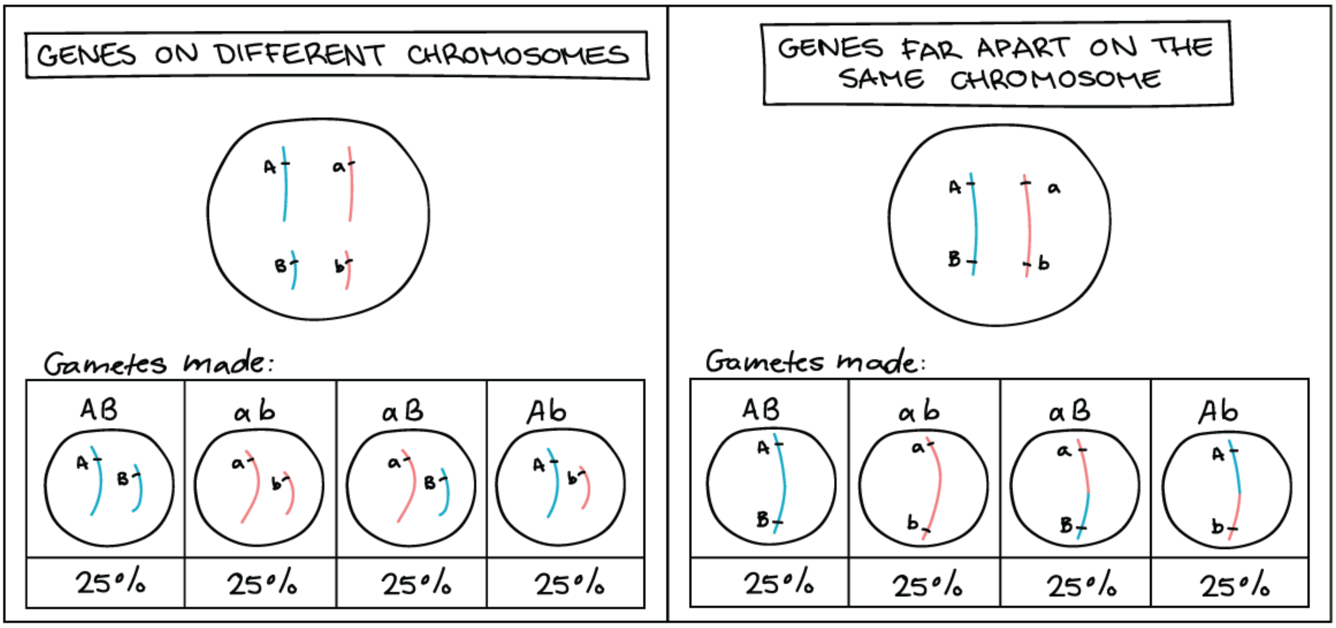
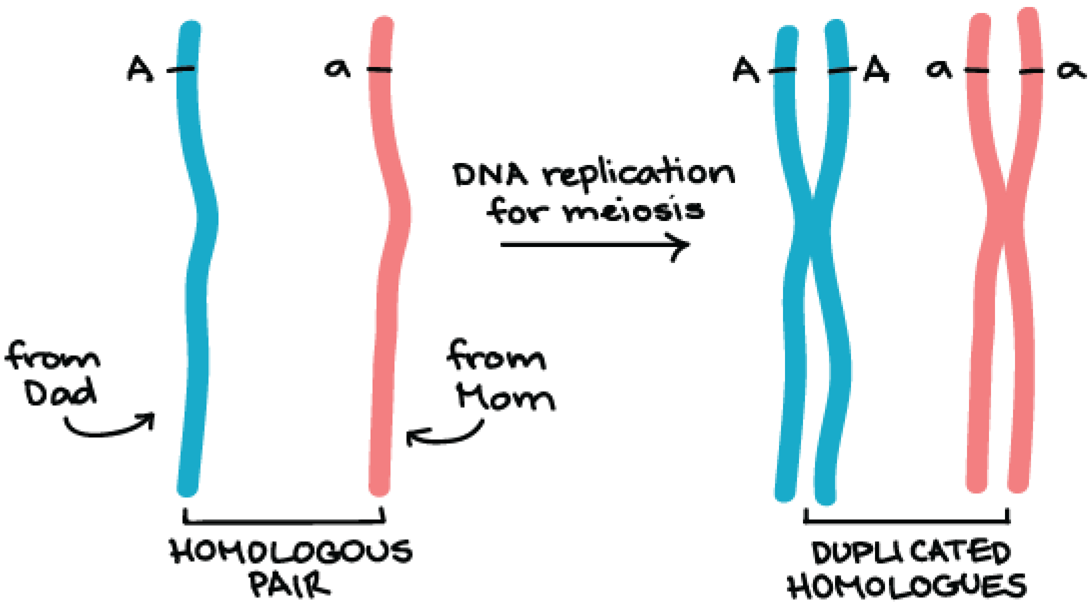
DISCUSSION AND EXPLANATION

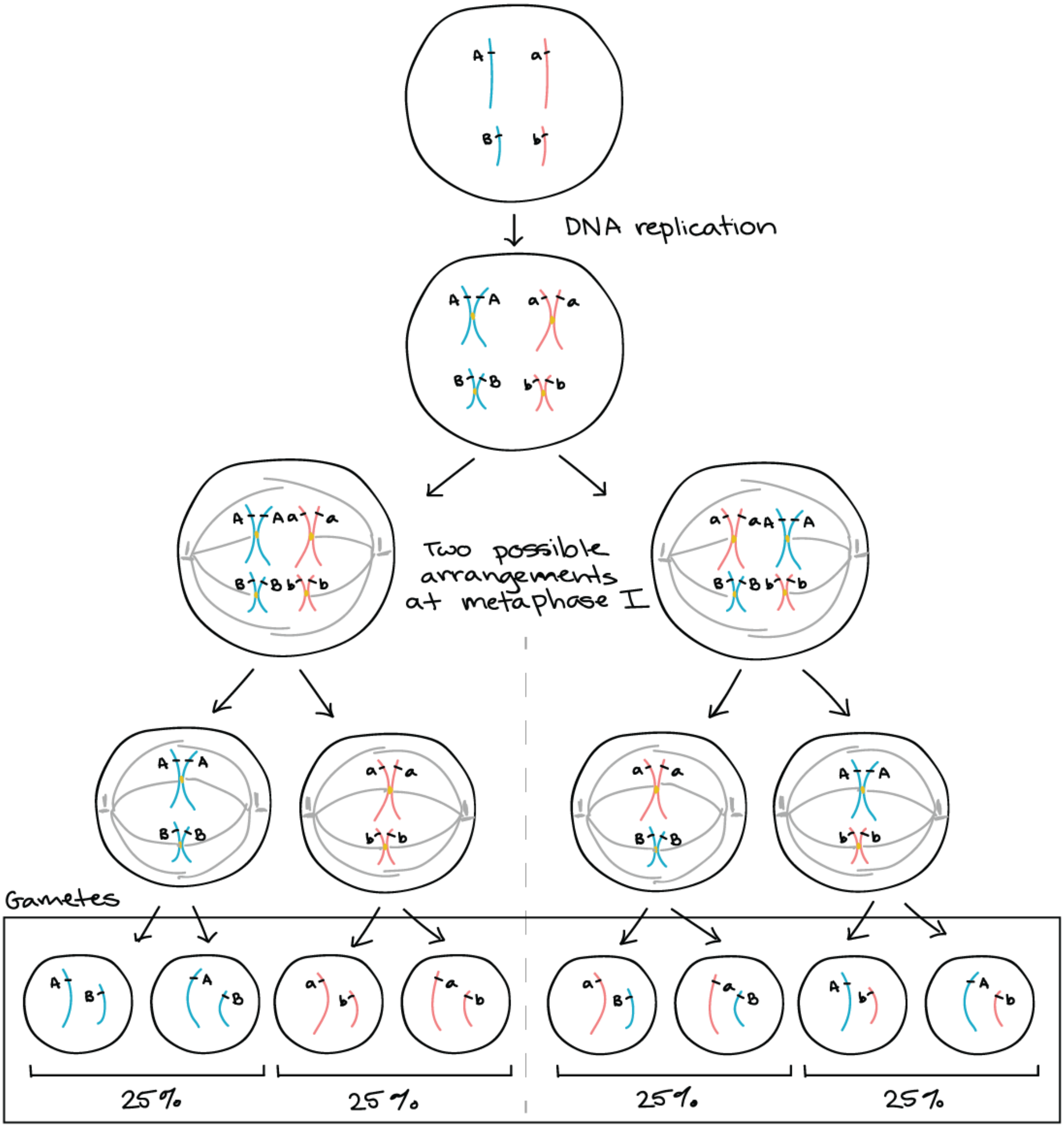
When genes are on separate chromosomes, or very far apart on the same chromosomes, they **assort independently**. That is, when the genes go into gametes, the allele received for one gene doesn't affect the allele received for the other.



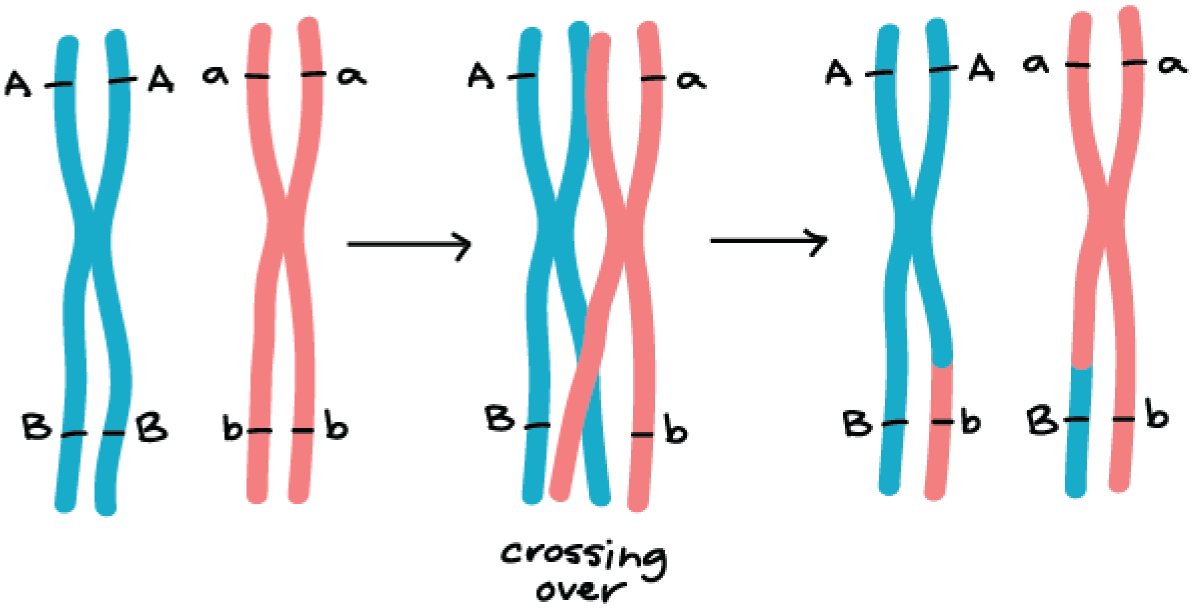
Genes on separate chromosomes assort independently because of the random orientation of homologous chromosome pairs during meiosis. **Homologous chromosomes** are paired chromosomes that carry the same genes, but may have different alleles of those genes. One member of each homologous pair comes from an organism's mom, the other from its dad.



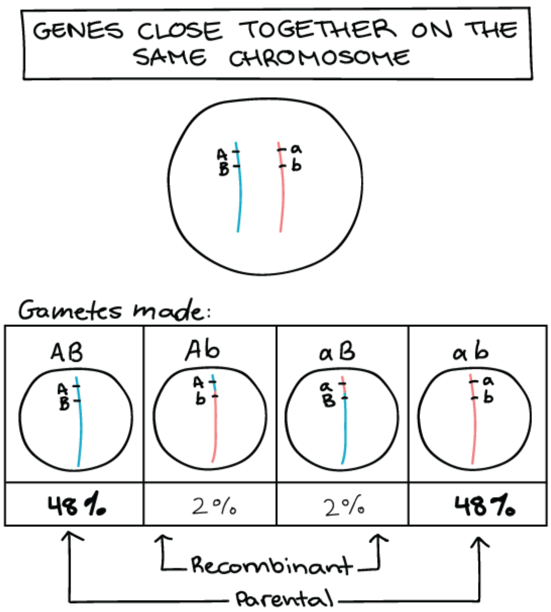
As illustrated in the diagram below, the homologues of each pair separate in the first stage of meiosis. In this process, which side the "dad" and "mom" chromosomes of each pair go to is random. When we are following two genes, this results in four types of gametes that are produced with equal frequency.



When genes are on the same chromosome but very far apart, they assort independently due to **crossing over** (**homologous recombination**). This is a process that happens at the very beginning of meiosis, in which homologous chromosomes randomly exchange matching fragments. Crossing over can put new alleles together in combination on the same chromosome, causing them to go into the same gamete.

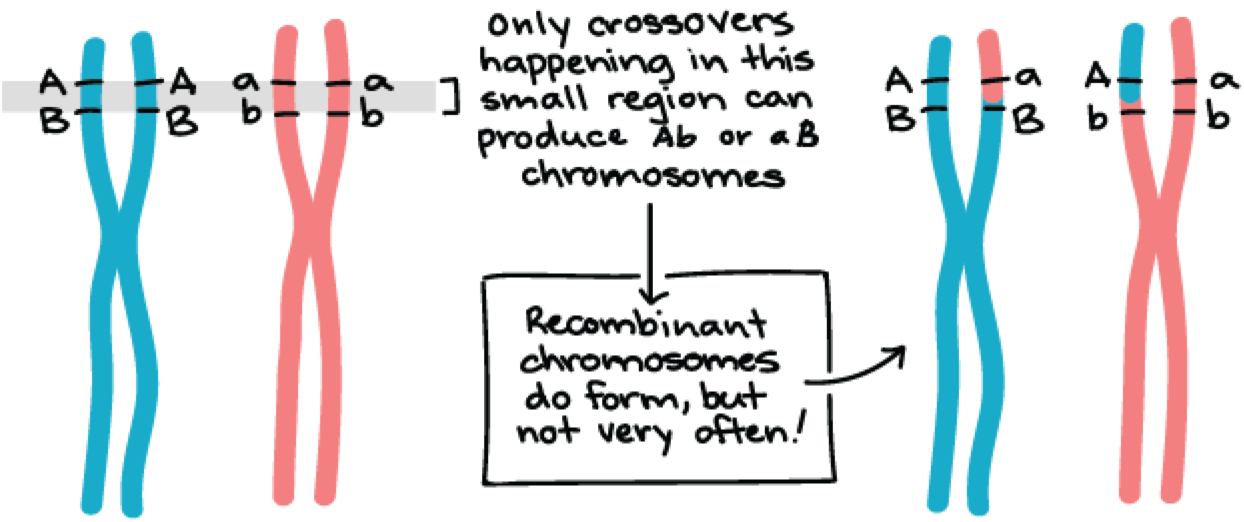


When genes are very close together on the same chromosome, crossing over still occurs, but the outcome (in terms of gamete types produced) is different. Instead of assorting independently, the genes tend to "stick together" during meiosis. That is, the alleles of the genes that are already together on a chromosome will tend to be passed as a unit to gametes. In this case, the genes are **linked**. For example, two linked genes might behave like this:



The common types of gametes contain **parental** configurations of alleles—that is, the ones that were already together on the chromosome in the organism before meiosis (i.e, on the chromosome it got from its parents). The rare types of gametes contain **recombinant** configurations of alleles, that is, ones that can only form if a recombination event (crossover) occurs in between the genes.

The basic reason is that crossovers between two genes that are close together are not very common. Crossovers during meiosis happen at more or less random positions along the chromosome, so the frequency of crossovers between two genes depends on the distance between them.



The **recombination frequency** between two genes (i.e., their degree of genetic linkage) is used to estimate their relative distance apart on the chromosome. Two very close-together genes will have very few recombination events and be tightly linked, while two genes that are slightly further apart will have more recombination events and be less tightly linked.