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Lecture – 9

Crossing over and Chromosome mapping

by

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Crossing over

Cytological basis of crossing over

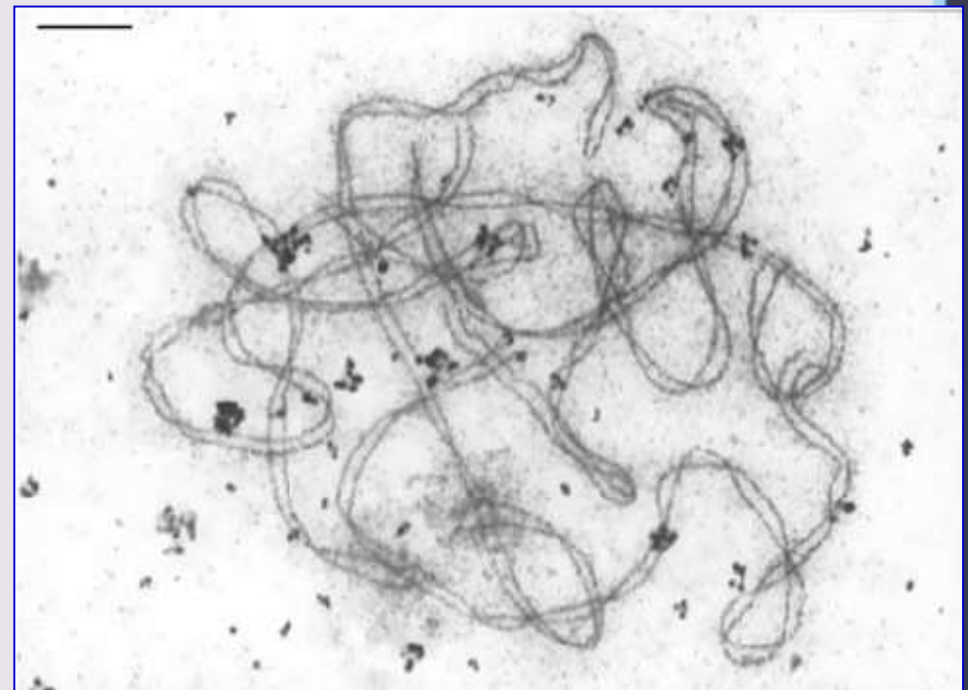
- ❖ F. Janssen first detected the **CHIASMATA** in Amphibians
- ❖ Direct evidence of crossing over was first obtained in 1931
- ❖ By C. Stern in *Drosophila* between genes for eye color (carnation/ red) and eye shape (Bar/ normal)
- ❖ By H. B. Creighton and B. McClintoc in Maize on chromosome no 9. The crossing over observed between the genes for Kernel color (colored/ colorless) and types of carbohydrates in the kernel (starchy/ waxy)



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Morgan and Crossing Over

- ❖ Chromosomes are long and contain many genes. To get individual genes re-shuffled, there needs to be a mechanism of recombining genes that are on the same chromosome. This mechanism is called “crossing over.
- ❖ Morgan proposed that the chiasmata visible on chromosomes were regions of crossing over.
- ❖ Occurs between non-sister chromatids.





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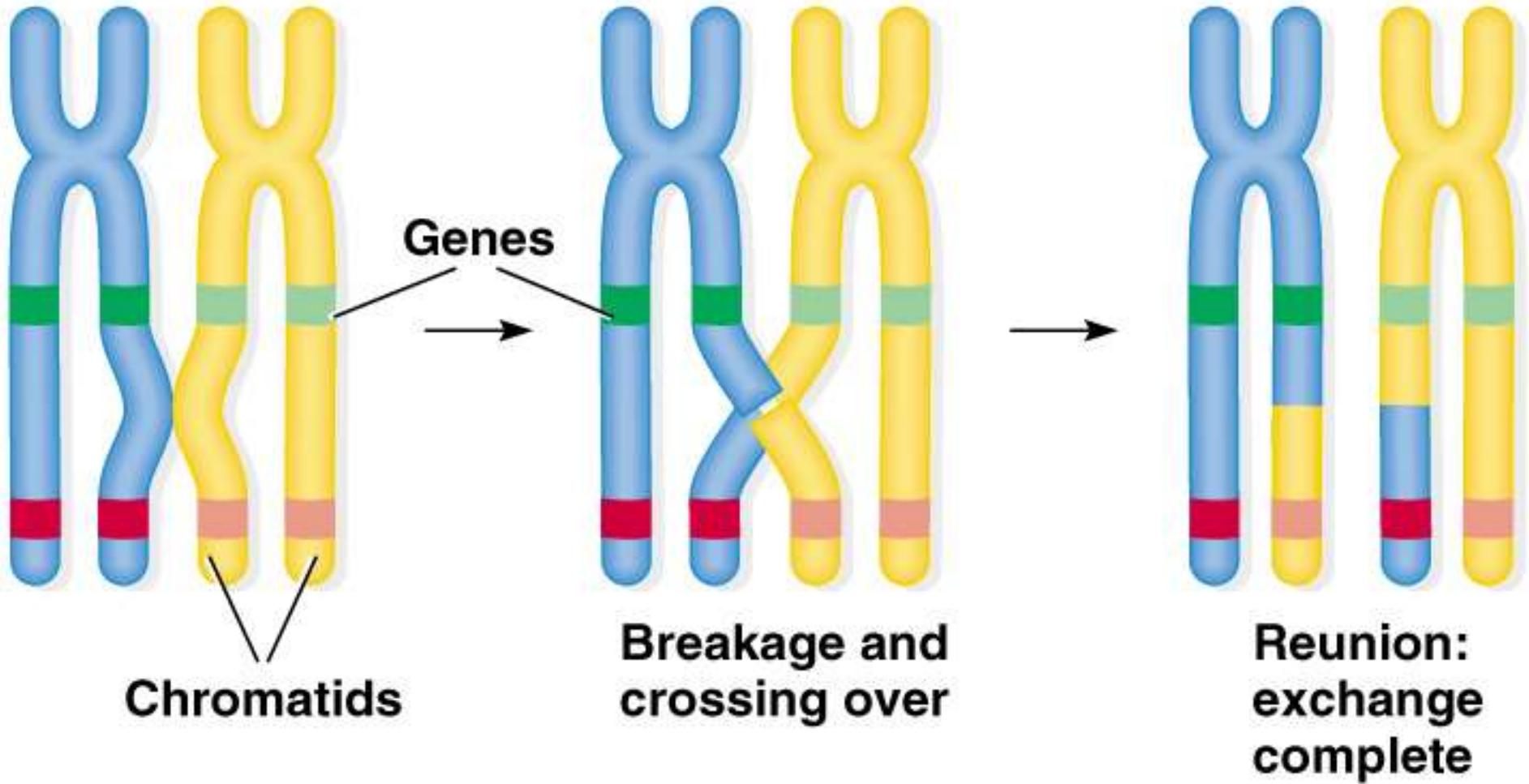
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- ❖ Crossing over occurs in prophase of meiosis 1, when the homologous chromosomes “synapse”, which means to pair closely with each other. DNA strands from the two chromosomes are matched with each other.
- ❖ The result of crossing over can be seen in the microscope as prophase continues, as X-shaped structures linking the homologues.
- ❖ The genetic consequence of crossing over is that each chromosome that goes into a gamete is a combination of maternal and paternal chromosomes.

Mechanism of crossing-over



Homologous chromosomes





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Significance of crossing over in Plant Breeding:

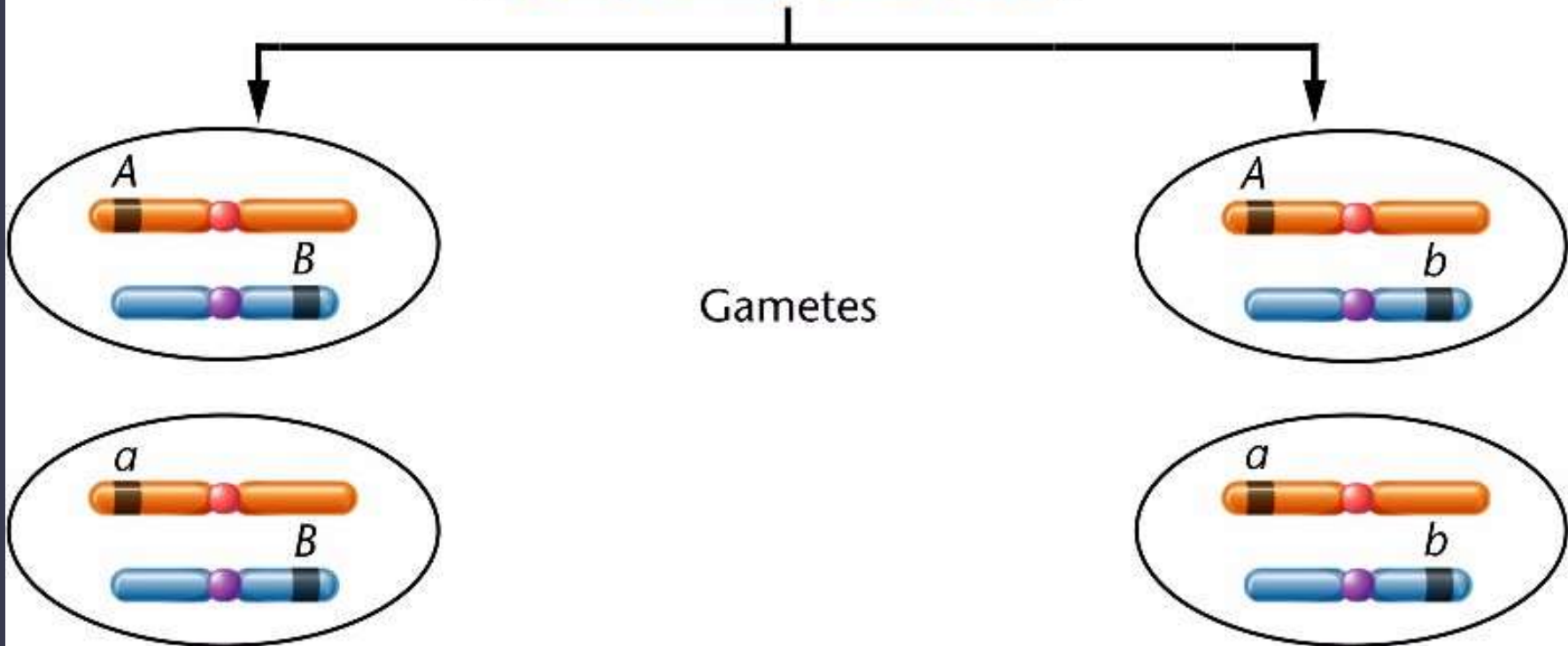
1. It increases variability
2. It helps to break linkages
3. It makes possible to construct chromosome maps

No Linkage: Independent Assortment



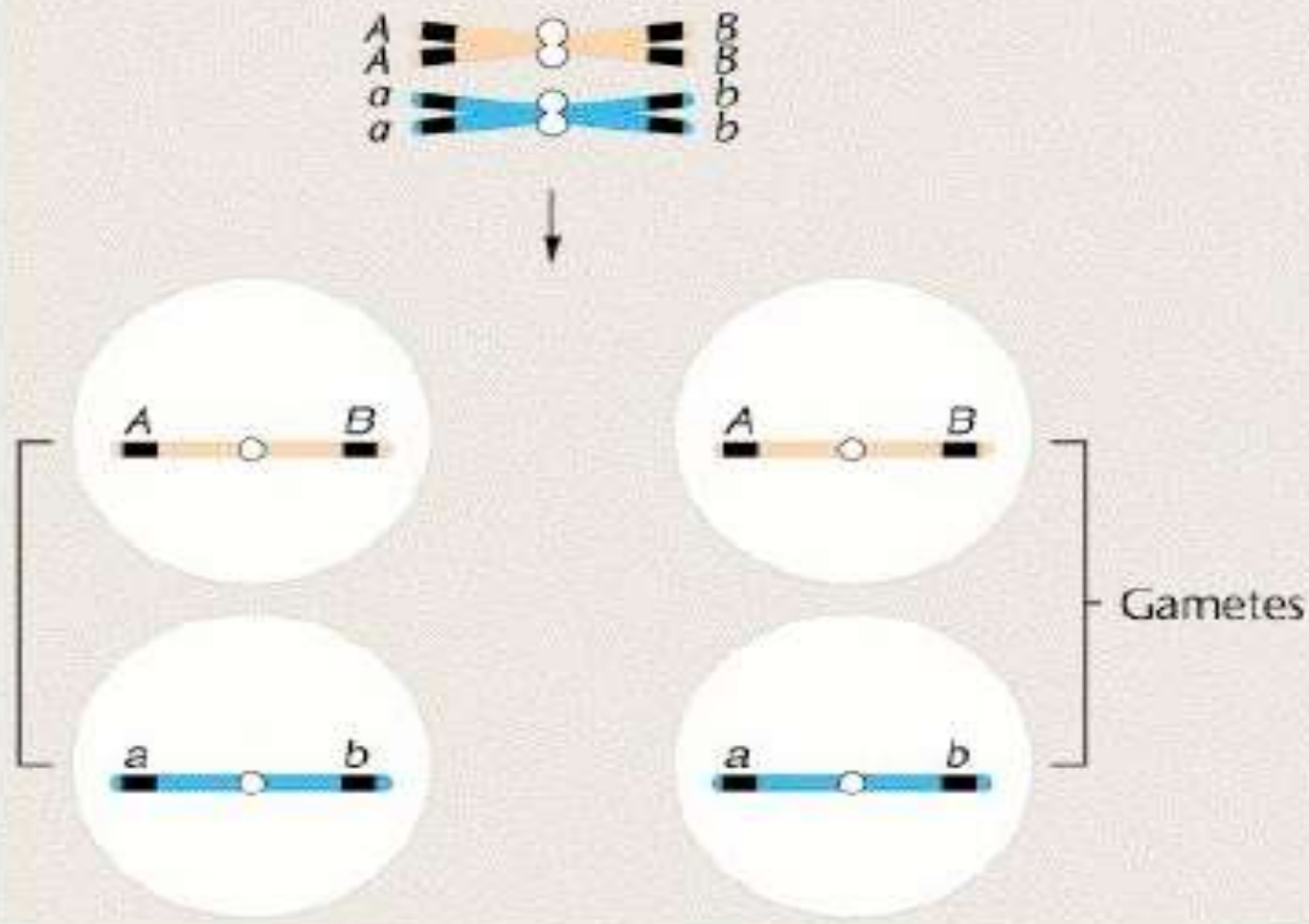
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Independent assortment: Two genes on two different homologous pairs of chromosomes



Linkage without Recombination

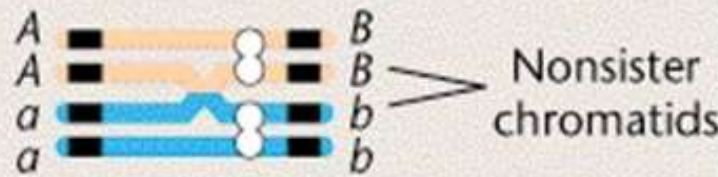
(b) Linkage between two genes on a single pair of homologs: no exchange occurs



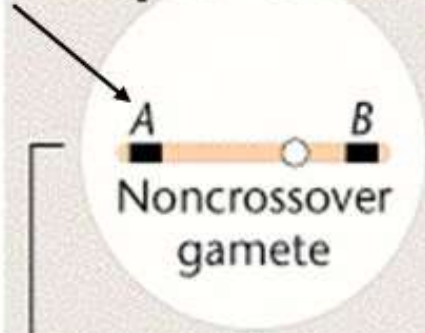


Linkage with recombination

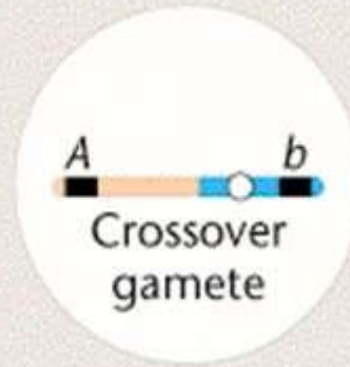
(c) Linkage between two genes on a single pair of homologs: exchange occurs between two nonsister chromatids



Most Frequent



Noncrossover gamete



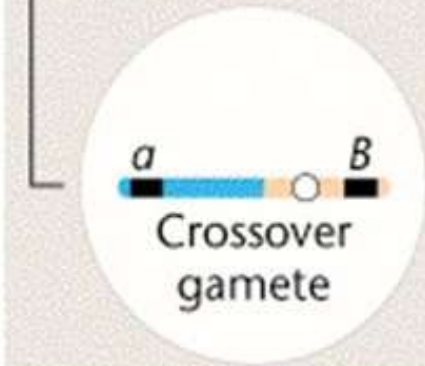
Crossover gamete

Linkage with Recombination

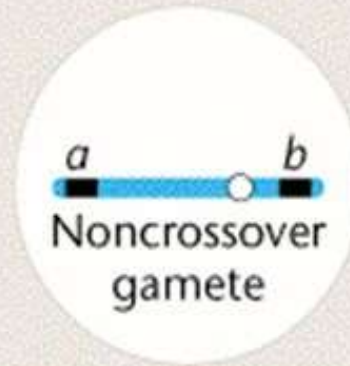
four types of gametes

in two frequency classes

Gametes



Crossover gamete



Noncrossover gamete

Most Frequent



Differences between crossing over and linkage

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Crossing over

Linkage

1	It leads to separation of linked genes	It keeps the genes together
2	It involves exchange of segments between non-sister chromatids of homologous chromosomes	It involves individual chromosomes
3	The frequency of crossing over can never exceed 50 %	The number of linkage groups can never be more than haploid chromosome number
4	It increases variability by forming new gene combinations	It reduces variability
5	It provides equal frequency of parental and recombinant types in test cross progeny	It produces higher frequency of parental types than recombinant types in test cross progeny

Double crossing over can occur in three different ways



No crossovers



One crossover

(Can be between any nonsister pair.)



Two crossovers

(Holding one crossover constant and varying the position of the second produces four equally frequent two-crossover meioses.)



Average two-crossover RF = $\frac{8}{16} = 50\%$



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- ❖ Don't confuse to frequency of crossing over with the frequency of crossover or recombinant chromosome.

No. of recombinant progeny from a test cross

$$\text{Frequency of crossing over (\%)} = \frac{\text{Total number of progeny}}{\text{Total number of progeny}} \times 100$$

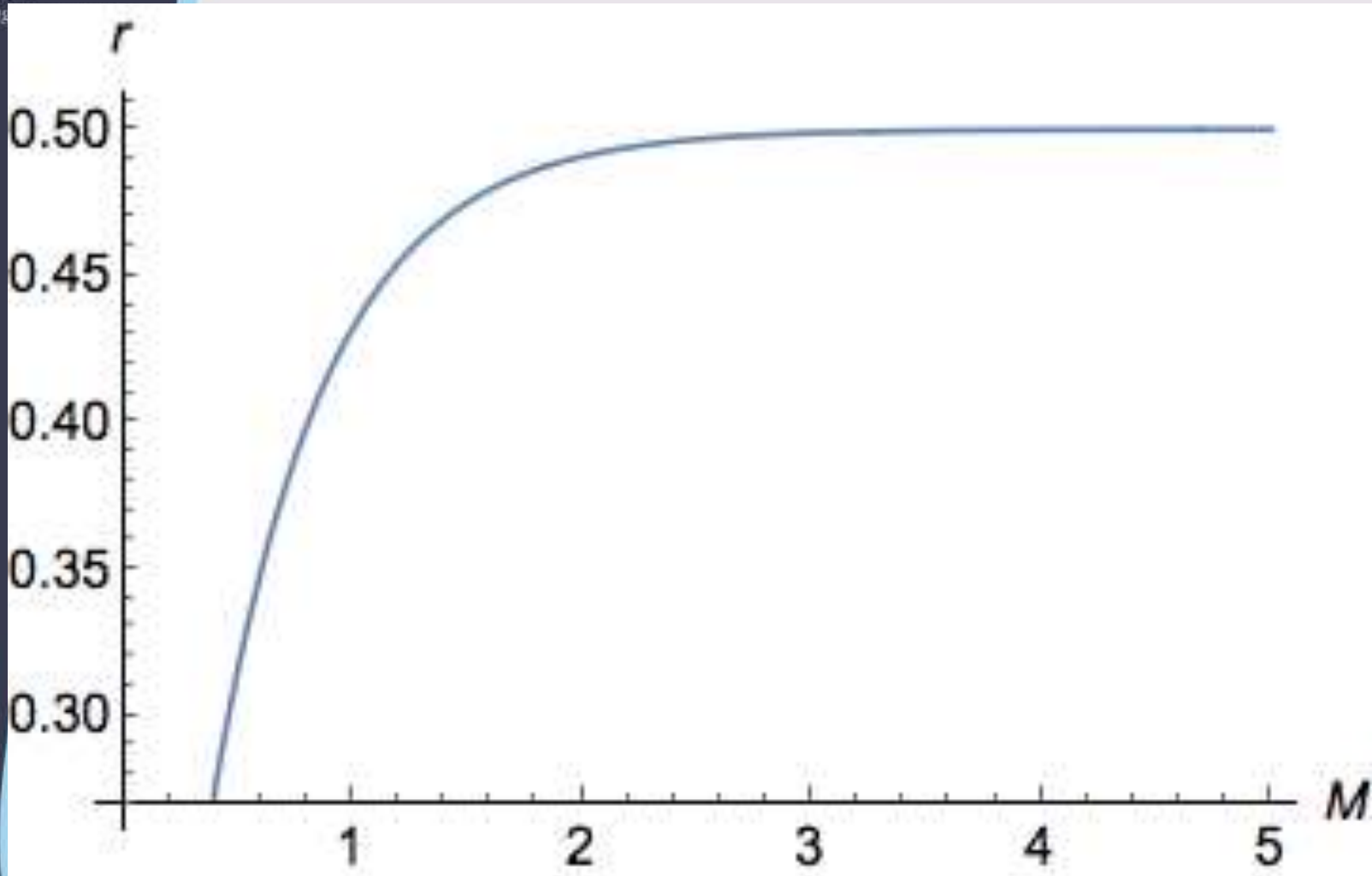
- ❖ If there is no chromatid interference occur than the ratio of two stranded to three stranded to four stranded double cross over will be 1:2:1
- ❖ Frequency of multiple crossover with an even no. exchanges (yielding parental combination) will approximately equal to the frequency of multiple crossover with an odd no. exchange (yielding recombinant combination) if considering any two non sister chromatids.



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**maximum recombination between
two linked genes is 50%**





Interference:

- ❖ The occurrence of crossing over in one region of a chromosome interferes with its occurrence in the neighboring segment is known as interference. It may also be defined as the tendency of one crossing over to prevent another crossing over from occurring in its vicinity.
- ❖ The term interference was coined by Muller.
 - ❖ It may be positive or negative interference (Eg: *Aspergillus*, bacteriophages.)
 - ❖ The effect of interference reduces as the distance from the first crossing over increases.
 - ❖ The intensity of interference may be estimated as coefficient of interference.

Coefficient of interference = 1 - coefficient of coincidence

- ❖ interference value between 0-1 = + ve interference
- ❖ in the absence of interference, coefficient of interference will be zero.



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Coincidence:

It refers to the occurrence of two or more distinct crossing overs at the same time in the same region of a pair of homologous chromosomes and as a result, a double cross over product is obtained. Coefficient of coincidence is estimated by using the formula:

$$\text{Coefficient of coincidence} = \frac{\text{Observed frequency of double cross over}}{\text{Expected frequency of double cross over}}$$

(The ratio between the observed and the expected frequencies of double crossovers is called coefficient of coincidence)

- in the absence of interference, the Coefficient of coincidence will be equal to 1.



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Detection of Linkage

- Test cross is the most common method of detecting the linkage. In this method, the F₁ heterozygous at two loci (AB/ab) is crossed to a double recessive parent (ab/ab) and the phenotypic ratio of test cross progeny is examined. If the phenotypic ratio of test crosses progeny shows 1:1:1:1 ratio of parental and recombinant genotypes, it indicates absence of linkage. If the frequency of parental types and recombinant types deviate significantly from the normal dihybrid test cross ratio of 1:1:1:1, it reveals presence of linkage between two genes under study.
- Another way to detect the presence or absence of linkage is to self-pollinate the individual heterozygous at two loci. If there is complete dominance at each locus and no epistasis, the segregation ratio of the progeny will be 9:3:3:1. Presence of linkage either in coupling or repulsion phase will lead to significant deviation from 9:3:3:1 ratio. The deviation of observed values from the expected ratio is tested with the help of χ^2 test.



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Detecting Linkage through Testcrosses

- Linked genes are used for mapping. They are found by looking for deviation from the frequencies expected from independent assortment.
- A testcross (one parent is homozygous recessive) works well for analyzing linkage
 - If the alleles are not linked, and the second parent is heterozygous, all four possible combinations of traits will be present in equal numbers in the progeny.
 - A significant deviation in this ratio (more parental and fewer recombinant types) indicates linkage.



Chromosome map

Chromosome maps can be prepared by genetical or cytological methods

- 1. Genetical method:** This is the general method and is based upon cross over data. The resulting map is the linkage map.
 - ❖ **Linkage map (cross over map or genetical map)** may be defined as a line on which the relative positions of genes proportional to the amount of crossing over between them is represented.
 - ❖ A rule widely followed in plotting genes is that if genes A and B are known to be linked and if a particular gene is found by experiment to be linked with gene A it must also be linked with gene B. This principle follows from the fact that two linked genes are on the same chromosome. The genes, which are linked together on the same chromosomes are called **syntenic genes**



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Genetic mapping of chromosomes is based on the following assumptions:

1. The genes are arranged in a linear order.
2. Crossing over is due to breaks in the chromatids
3. Crossing over occurs by chance and is at random
4. The percentage of crossing over between the genes is an index of their distance apart



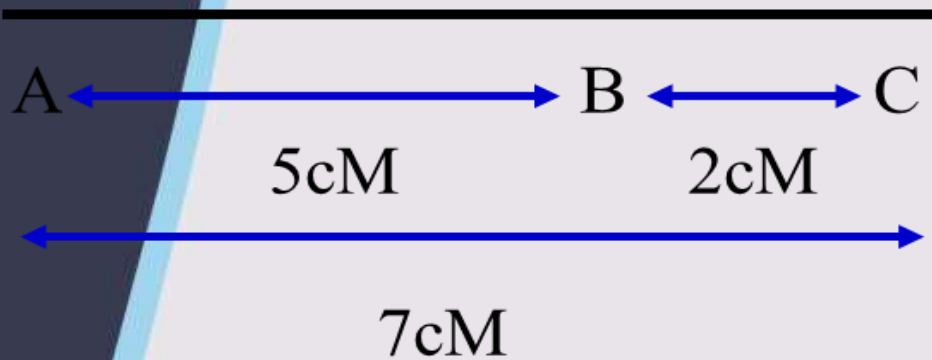
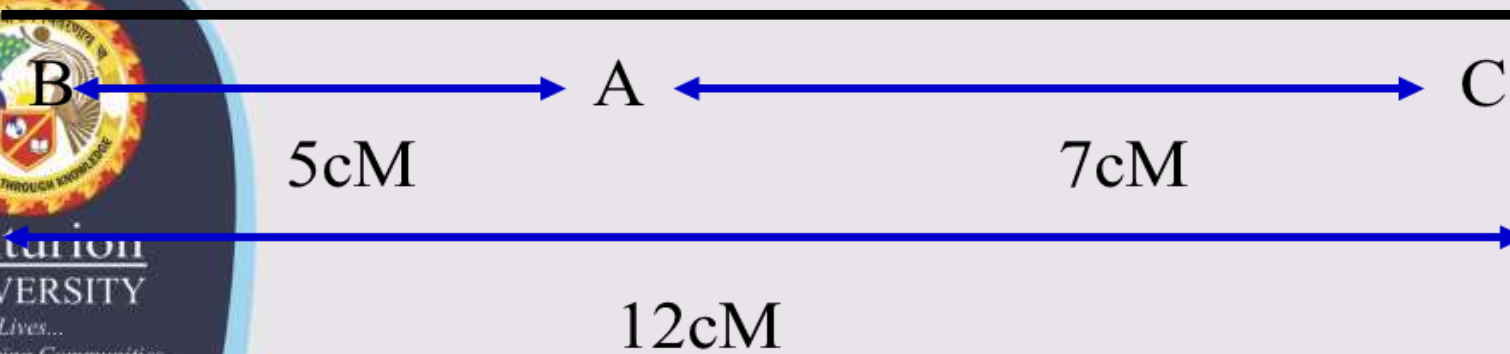
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Map distance:

- ❖ Recombination frequencies between the linked genes are determined from appropriate testcrosses. These percent frequencies are used as map units for preparing linkage maps.
- ❖ A map unit is that distance in a chromosome, which permits one percent recombination (crossing over) between two linked genes.
- ❖ A map unit is also called a centi-Morgan, after the name of the scientist Morgan, who first constructed the linkage map in *Drosophila*.
- ❖ Thus 5 % crossing over between genes A and B is taken to mean that they are situated 5 map units of distance apart on the same chromosome. If a third gene C with 7 % crossing over between A and C is included the relationship of linkage between the three genes A, B and C is indicated as below:



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To choose the correct one between these two alternatives, one more information i.e. either the order of arrangement of the three genes or the cross over value between B and C is required. Eg: If the crossover value between B and C is found to be 2 % by actual experiments, the second arrangement is the correct one.



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What is a three point cross?

Three point cross refers to using 3 points (genes) to determine the order and distance between the genes.

Why are three point crosses important?

By solving a three point cross you can determine two important things:

- ❑ order of the genes on a chromosome.
- ❑ determine the distance (in map units) between each pair of genes.



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Conditions for a Three Point Cross

- ❖ The genotype of the organism must be heterozygous at all loci that will be used for the cross. Homozygous alleles do not allow for differentiation of origin of alleles.
- ❖ The genotypes of the offspring must be able to be observed in order to determine which alleles have been inherited.
- ❖ There must be a sufficient number of offspring produced to give a representative sample this is large enough to get accurate results.



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Nomenclature in 3-pt crosses

- Mutant alleles are represented by letters (s, v, w, sc, etc.)
- Wildtype (non mutant) alleles are signified by a + sign.
- All three alleles that are on a single chromosome are written together.
- $s + v$ = two mutant alleles and one wildtype allele
- $+ + +$ = all wildtype alleles
- SCO- single crossover
- DCO-double crossover



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