Hypothesis: *pr* and *vg* are independently assorted

		Observed
Parental	$pr^{+} \cdot vg^{+}$	86
	$pr \cdot vg$	93
Recombinant	$pr^{+} \cdot vg$	34
	$pr \cdot vg^{+}$	55
	Total: 268	

Phenotype	Expected
pr+ vg+	67
pr vg	67
pr+ vg	67
pr vg+	67

$$\chi 2=\sum(O-E)^2/E$$

Phenotype	Observed	Expected	$(O-E)^2$	$(O-E)^2/E$
pr+ vg+	86	67	361	5.3880597
pr vg	93	67	676	10.0895522
pr+ vg	34	67	1089	16.2537313
pr vg+	55	67	144	2.14925373
			SUM	33.880597

Critical value

Critical value is then used to determine the confidence level

TABLE 3-1 Critical Values of the χ^2

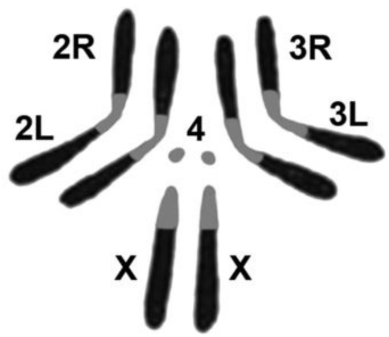
df	p									df
	0.995	**0.975**	**0.9**	**0.5**	**0.1**	**0.05**	**0.025**	**0.01**	**0.005**	
1	.000	.000	0.016	0.455	2.706	3.841	5.024	6.635	7.879	1
2	0.010	0.051	0.211	1.386	4.605	5.991	7.378	9.210	10.597	2
3	0.072	0.216	0.584	2.366	6.251	7.815	9.348	11.345	12.838	3
4	0.207	0.484	1.064	3.357	7.779	9.488	11.143	13.277	14.860	4
5	0.412	0.831	1.610	4.351	9.236	11.070	12.832	15.086	16.750	5
6	0.676	1.237	2.204	5.348	10.645	12.592	14.449	16.812	18.548	6
7	0.989	1.690	2.833	6.346	12.017	14.067	16.013	18.475	20.278	7
8	1.344	2.180	3.490	7.344	13.362	15.507	17.535	20.090	21.955	8
9	1.735	2.700	4.168	8.343	14.684	16.919	19.023	21.666	23.589	9
10	2.156	3.247	4.865	9.342	15.987	18.307	20.483	23.209	25.188	10
11	2.603	3.816	5.578	10.341	17.275	19.675	21.920	24.725	26.757	11
12	3.074	4.404	6.304	11.340	18.549	21.026	23.337	26.217	28.300	12
13	3.565	5.009	7.042	12.340	19.812	22.362	24.736	27.688	29.819	13
14	4.075	5.629	7.790	13.339	21.064	23.685	26.119	29.141	31.319	14
15	4.601	6.262	8.547	14.339	22.307	24.996	27.488	30.578	32.801	15

df: degree of freedom (number of independent value -1)

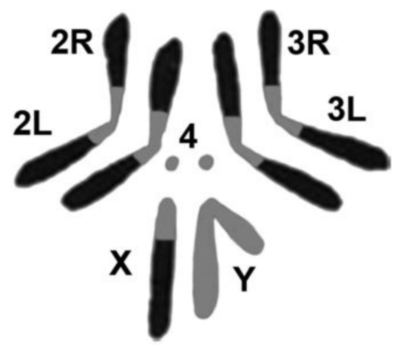
p=0.05 means that there is 5% chance of getting observed number even if independent assortment is true. If *p*=<0.05, you can reject the hypothesis with the confidence level of 95% or greater

Linkage & Mapping

Ch4.1- Ch4.2



Female



Males

Morgan's finding

two recessive mutations

pr: purple eyes instead of red
vg: small wings

P	$pr/pr \cdot vg/vg \times pr^+/pr^+ \cdot vg^+/vg^+$
	$\downarrow$
Gametes	$pr \cdot vg \quad pr^+ \cdot vg^+$
	$\downarrow$
F_1 dihybrid	$pr^+/pr \cdot vg^+/vg$

Testcross

$$pr^+/pr \cdot vg^+/vg \, ♀ \times pr/pr \cdot vg/vg \, ♂$$

F$_1$ dihybrid female — Tester male

Parental	$pr^+ \cdot vg^+$	1339
	$pr \cdot vg$	1195
Recombinant	$pr^+ \cdot vg$	151
	$pr \cdot vg^+$	154
		2839

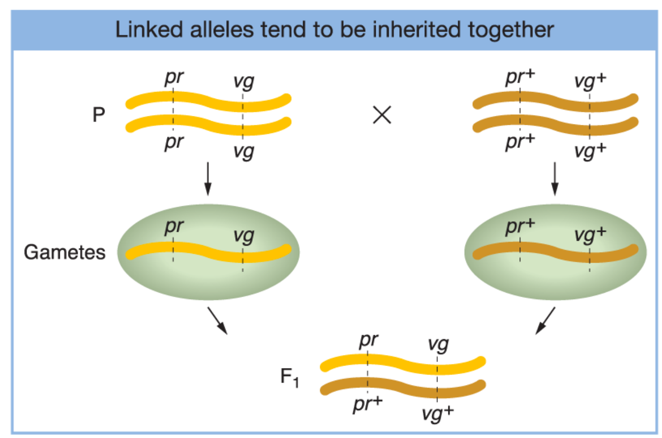


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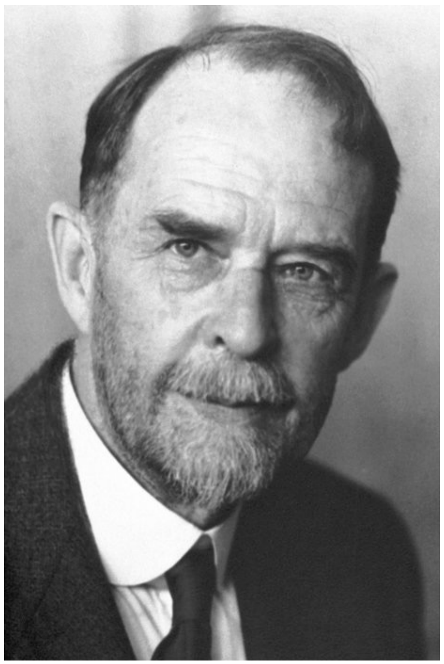
Fig 4-2

Thomas Hunt Morgan: “Chromosome theory of inheritance”



The Nobel Prize in Physiology or Medicine 1933

“His work confirmed that genes are stored in chromosomes inside cell nuclei. He came to understand that genes are organized in a long row inside chromosomes and how traits related to each other correspond to genes that lie close to one another on the chromosomes. He also discovered the crossover phenomenon, in which parts of different chromosomes can trade places with one another.”

https://www.nobelprize.org/prizes/medicine/1933/morgan/facts/

Recombinants are produced during meiosis

$pr^+ \cdot vg^+$	1339
$pr \cdot vg$	1195
$pr^+ \cdot vg$	151
$pr \cdot vg^+$	154
	2839

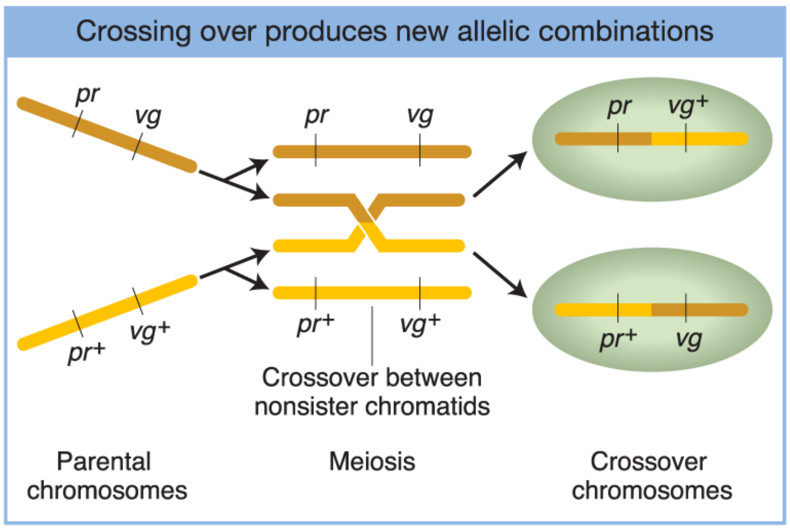


Fig 4-3

Crossover

Fig 4-4

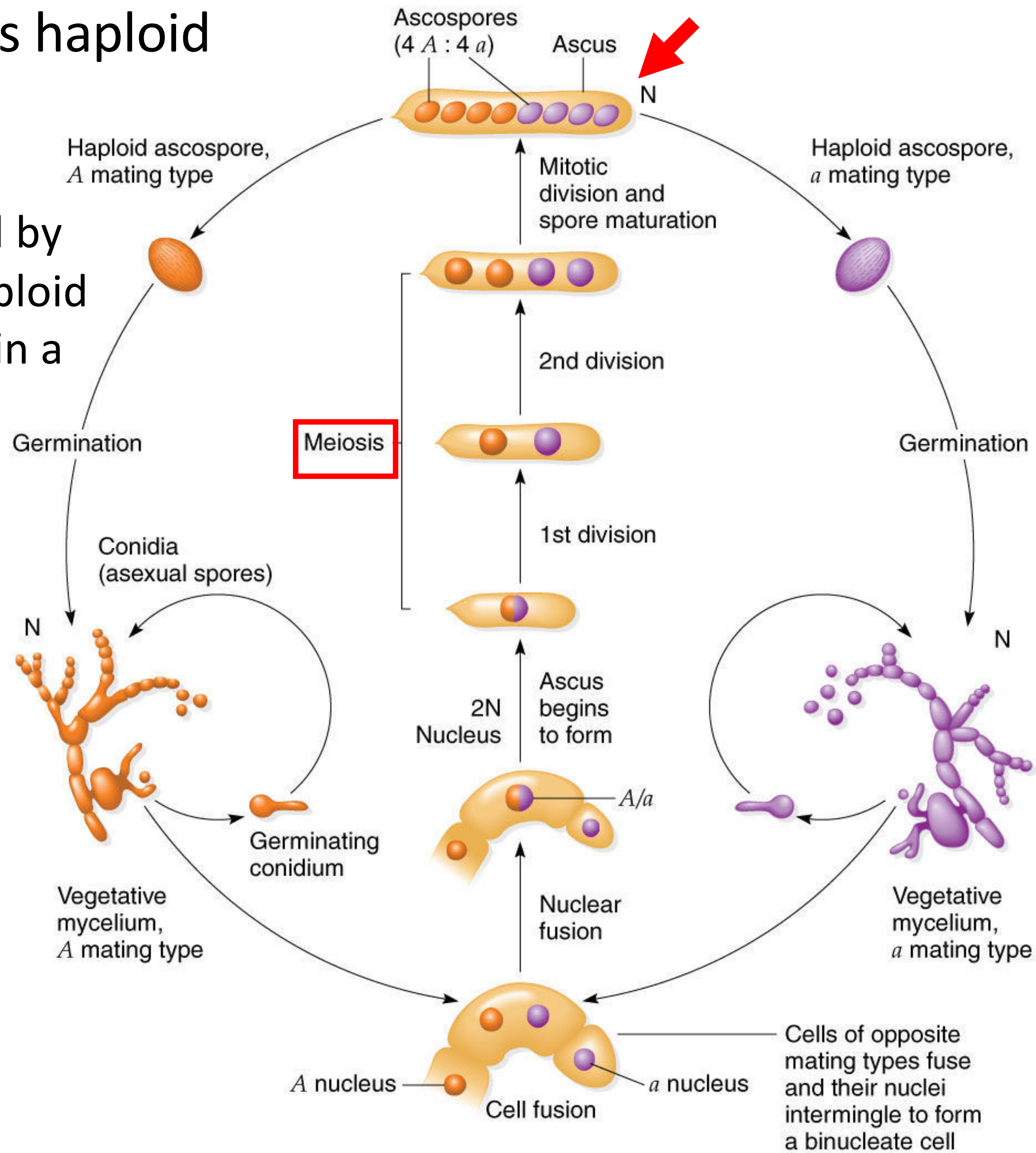
When does crossover take place during meiosis, before or after DNA replication?

Could there be multiple crossovers in a single meiosis event?

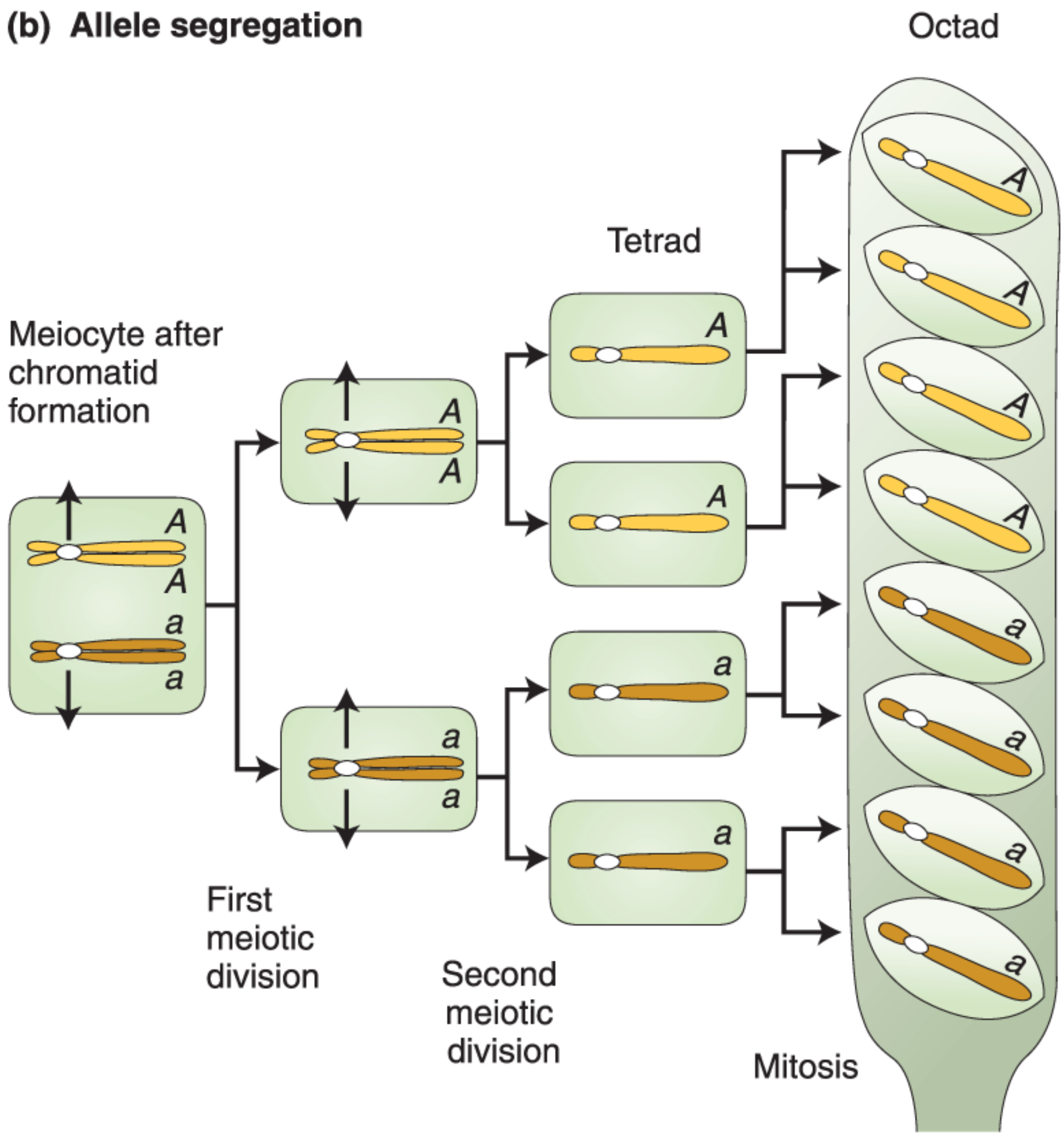
Neurospora Life cycle

Mold, grows as haploid

Ascospores produced by meiosis of a single diploid cell remain together in a sac called ***ascus***.



Ascus contain products of a single meiotic event



Multiple crossovers between two haploids: *ABC X abc*

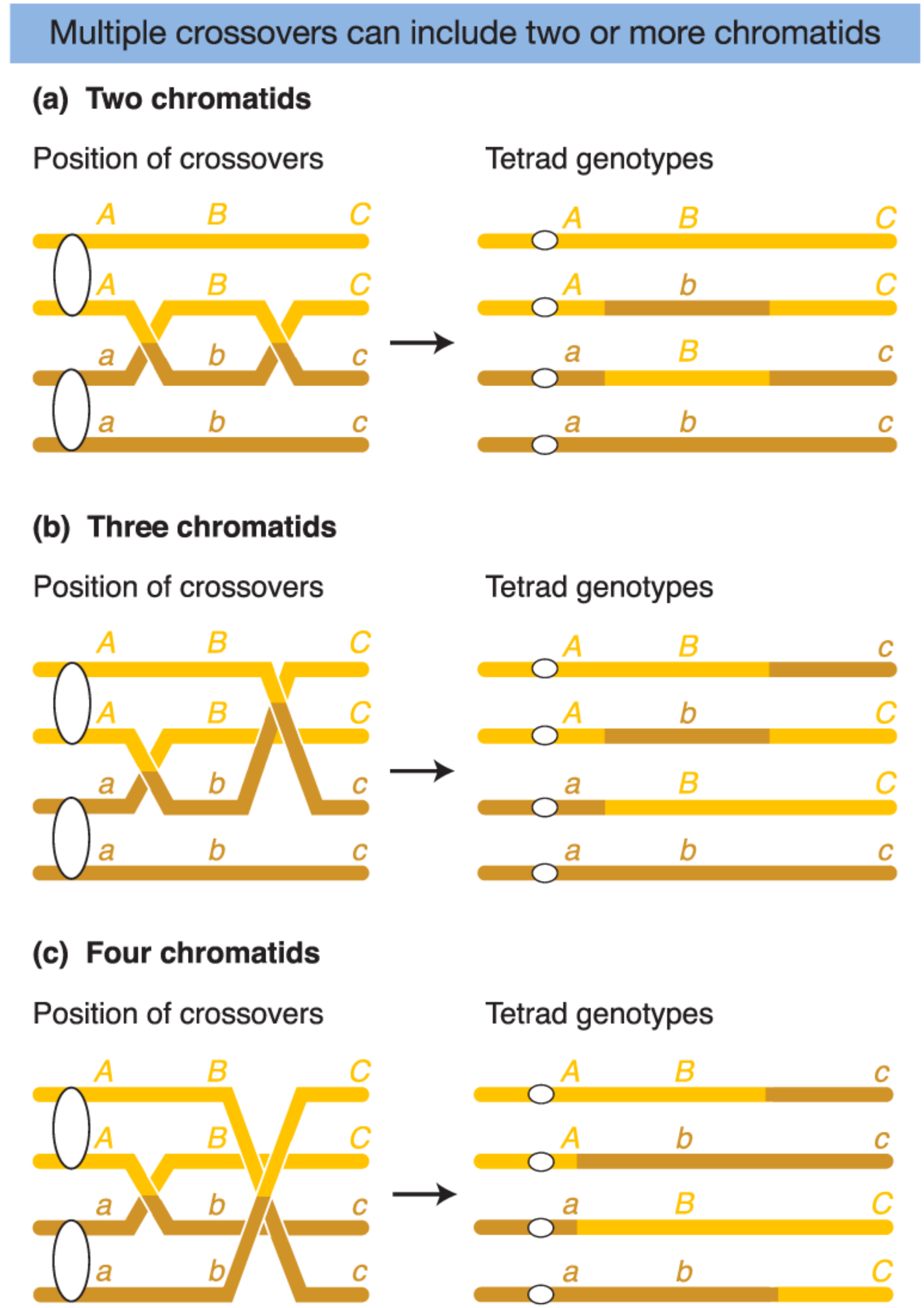
ABC
abc

ABC
ABC
abc
abc

ABC
AbC
aBc
acb

ABc
AbC
aBC
abc

ABc
Abc
aBC
abC



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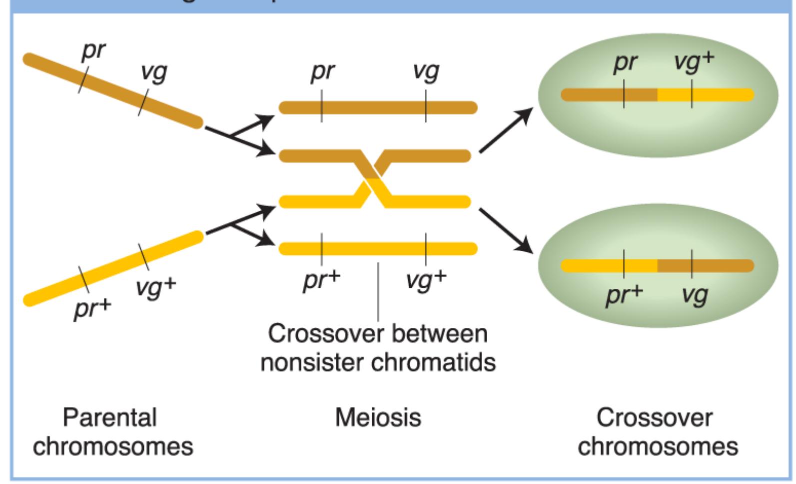
Crossover and the physical distance of the genes

Farther apart the genes are, they are more likely to crossover, higher chance of producing recombinant.

Parental	$pr^{+} \cdot vg^{+}$	1339
	$pr \cdot vg$	1195
Recombinant	$pr^{+} \cdot vg$	151
	$pr \cdot vg^{+}$	154
		2839


Chiasmata are the sites of crossing over

Fig 4-4



Crossing over produces new allelic combinations

Frequency of recombinant production is determined by their physical distance!!!

Genetic map unit (centimorgan)

1 genetic map unit (m.u.) = the frequency at which one out of 100 meiosis products is recombinant.

$pr^{+} \cdot vg^{+}$	1339
$pr \cdot vg$	1195
$pr^{+} \cdot vg$	151
$pr \cdot vg^{+}$	154
	2839

(151+154)/2839 X 100 = 10.7%

Therefor the distance between pr and vg is 10.7 m.u. (centimorgan (cM) in honor of Thomas Hunt Morgan).

In theory, RF of two genes cannot exceed 50%, independent assortment.

Alfred Sturtevant

A student of Thomas Morgan

FRs between linked genes can generate a map of a genome.

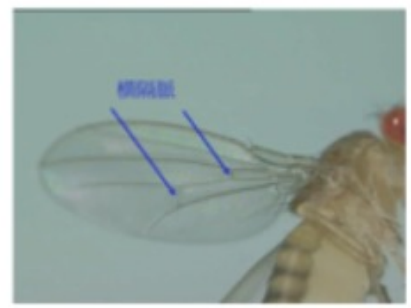
Three point testcross

v vermillion eyes

("vermillion")

cv wings lacking cross veins

("cross-veinless")



ct cut or snipped wing edges

("cut")

Three point testcross

P	$v^+/v^+ \cdot cv/cv \cdot ct/ct \times v/v \cdot cv^+/cv^+ \cdot ct^+/ct^+$	
	$\downarrow$	
Gametes	$v^+ \cdot cv \cdot ct$	$v \cdot cv^+ \cdot ct^+$
F_1 trihybrid	$v/v^+ \cdot cv/cv^+ \cdot ct/ct^+$	

$$v/v^+ \cdot cv/cv^+ \cdot ct/ct^+ ♀ \quad \times \quad v/v \cdot cv/cv \cdot ct/ct ♂$$

F_1 trihybrid female — Tester male

parental types: $v \bullet cv^{+} \bullet ct^{+}$ & $v^{+} \bullet cv \bullet ct$

Gametes of F1

$v \cdot cv^{+} \cdot ct^{+}$	580
$v^{+} \cdot cv \cdot ct$	592
$v \cdot cv \cdot ct^{+}$	45
$v^{+} \cdot cv^{+} \cdot ct$	40
$v \cdot cv \cdot ct$	89
$v^{+} \cdot cv^{+} \cdot ct^{+}$	94
$v \cdot cv^{+} \cdot ct$	3
$v^{+} \cdot cv \cdot ct^{+}$	5
	1448
	RF

parental types: $v \bullet cv+ \bullet ct+$ & $v+ \bullet cv \bullet ct$

Gametes of F1		Recombinant for loci: v and cv
$v \cdot cv^+ \cdot ct^+$	580	
$v^+ \cdot cv \cdot ct$	592	
$v \cdot cv \cdot ct^+$	45	R
$v^+ \cdot cv^+ \cdot ct$	40	R
$v \cdot cv \cdot ct$	89	R
$v^+ \cdot cv^+ \cdot ct^+$	94	R
$v \cdot cv^+ \cdot ct$	3	
$v^+ \cdot cv \cdot ct^+$	5	
	1448	268
	RF	18.5%

parental types: $v \bullet cv^+ \bullet ct^+$ & $v^+ \bullet cv \bullet ct$

Gametes of F1		Recombinant for loci: v and ct
$v \cdot cv^+ \cdot ct^+$	580	
$v^+ \cdot cv \cdot ct$	592	
$v \cdot cv \cdot ct^+$	45	
$v^+ \cdot cv^+ \cdot ct$	40	
$v \cdot cv \cdot ct$	89	R
$v^+ \cdot cv^+ \cdot ct^+$	94	R
$v \cdot cv^+ \cdot ct$	3	R
$v^+ \cdot cv \cdot ct^+$	5	R
	1448	191
	RF	13.2%

parental types: $v \bullet cv+ \bullet ct+$ & $v+ \bullet cv \bullet ct$

Gametes of F1		Recombinant for loci *cv* and *ct*
$v \cdot cv^+ \cdot ct^+$	580	
$v^+ \cdot cv \cdot ct$	592	
$v \cdot cv \cdot ct^+$	45	R
$v^+ \cdot cv^+ \cdot ct$	40	R
$v \cdot cv \cdot ct$	89	
$v^+ \cdot cv^+ \cdot ct^+$	94	
$v \cdot cv^+ \cdot ct$	3	R
$v^+ \cdot cv \cdot ct^+$	5	R
	1448	93
	RF	6.4%

parental types: $v \bullet cv^{+} \bullet ct^{+}$ & $v^{+} \bullet cv \bullet ct$

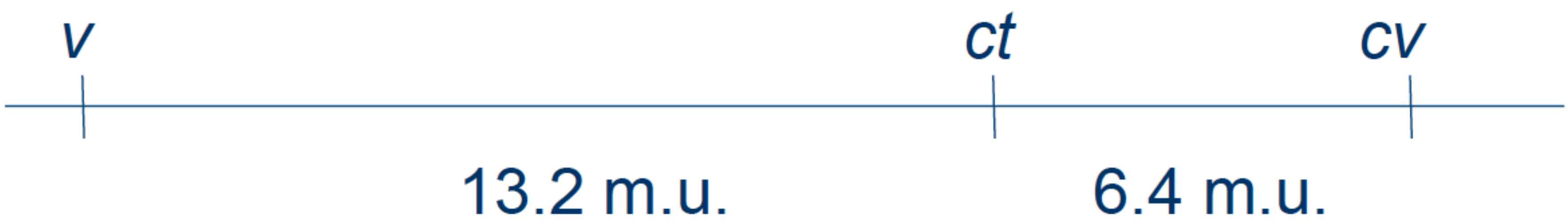
Gametes of F1		Recombinant for loci		
		v and cv	v and ct	cv and ct
$v \cdot cv^{+} \cdot ct^{+}$	580			
$v^{+} \cdot cv \cdot ct$	592			
$v \cdot cv \cdot ct^{+}$	45	R		R
$v^{+} \cdot cv^{+} \cdot ct$	40	R		R
$v \cdot cv \cdot ct$	89	R	R	
$v^{+} \cdot cv^{+} \cdot ct^{+}$	94	R	R	
$v \cdot cv^{+} \cdot ct$	3		R	R
$v^{+} \cdot cv \cdot ct^{+}$	5		R	R
	1448	268	191	93
	RF	18.5%	13.2%	6.4%

v & *cv* = 18.5%

v & *ct* = 13.2%

cv & *ct* = 6.4%

Therefore the map looks like:

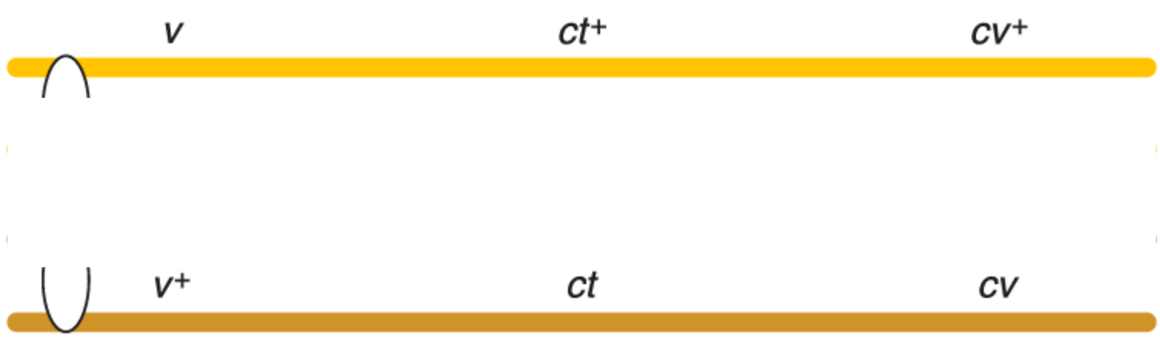


But 13.2 + 6.4 = 19.6 not 18.5……. Why?

parental types: *v • cv+ • ct+* & *v+ • cv • ct*

		Recombinant for loci		
Gametes		*v* and *cv*	*v* and *ct*	*cv* and *ct*
$v \cdot cv^+ \cdot ct^+$	580			
$v^+ \cdot cv \cdot ct$	592			
$v \cdot cv \cdot ct^+$	45	R		R
$v^+ \cdot cv^+ \cdot ct$	40	R		R
$v \cdot cv \cdot ct$	89	R	R	
$v^+ \cdot cv^+ \cdot ct^+$	94	R	R	
$v \cdot cv^+ \cdot ct$	3		R	R
$v^+ \cdot cv \cdot ct^+$	5		R	R
	1448	268	191	93

Double recombinants arising from two crossovers



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Two recombination events between v and cv: 2(3+5) + 268 = 284 recombination events
284/1448 X 100 = 19.6

Map of Drosophila genes