# 10.1 Meiosis (AHL)

## Essential idea: Meiosis leads to independent assortment of chromosomes and unique composition of alleles in daughter cells.

The family portrait shows large amounts of variation within a family despite sharing a lot of genes. This shows the potential of crossing over and independent assortment to create near infinite variation in gametes and hence in offspring too.

By Chris Paine

https://bioknowledgy.weebly.com/

https://upload.wikimedia.org/wikipedia/commons/9/95/Coloured-family.jpg

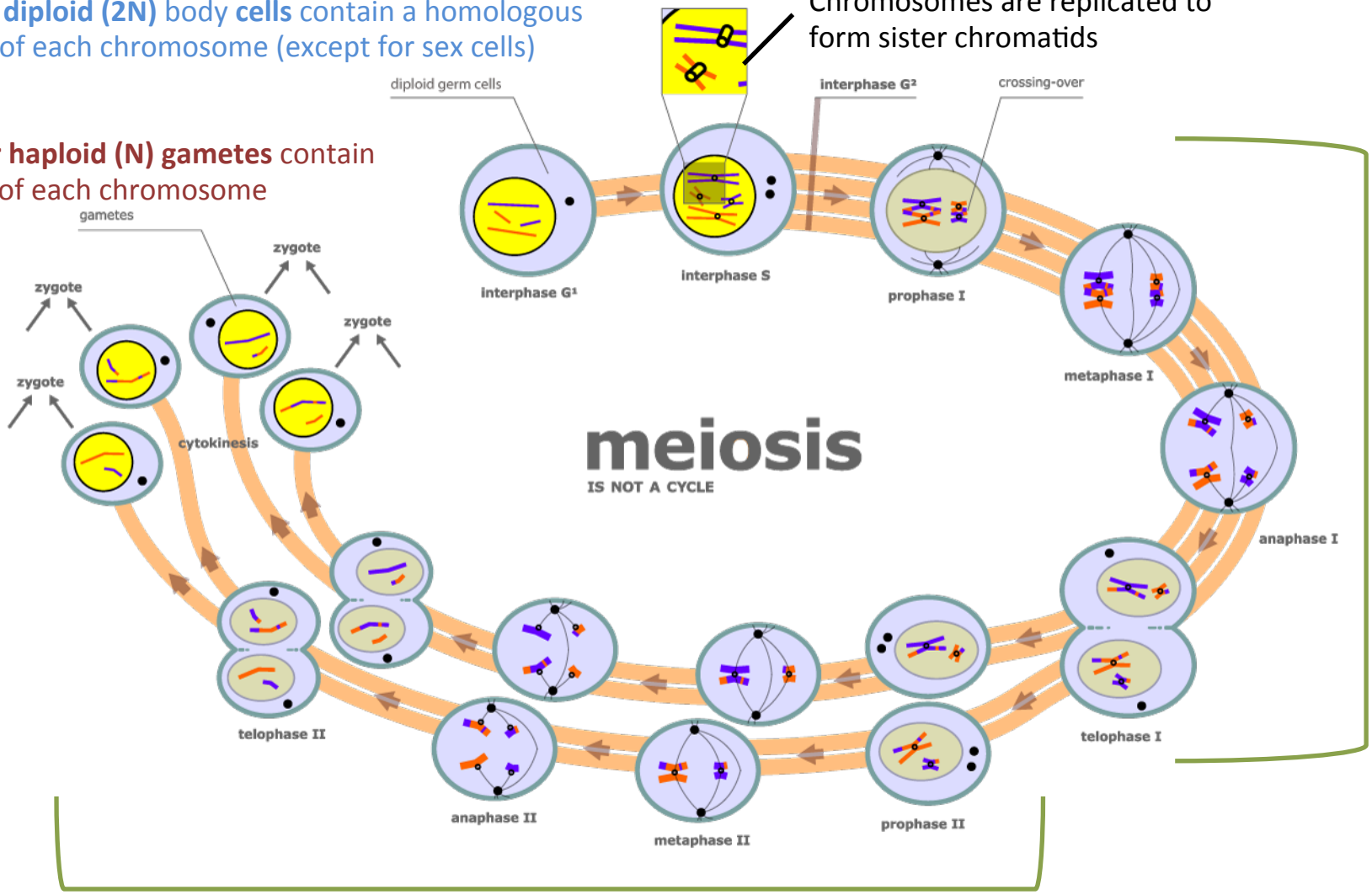
# Understandings, Applications and Skills

| | Statement | Guidance |
|---|---|---|
| 10.1.U1 | Chromosomes replicate in interphase before meiosis. | |
| 10.1.U2 | Crossing over is the exchange of DNA material between non-sister homologous chromatids. | |
| 10.1.U3 | Crossing over produces new combinations of alleles on the chromosomes of the haploid cells. | |
| 10.1.U4 | Chiasmata formation between non-sister chromatids can result in an exchange of alleles. | |
| 10.1.U5 | Homologous chromosomes separate in meiosis I. | |
| 10.1.U6 | Sister chromatids separate in meiosis II. | |
| 10.1.U7 | Independent assortment of genes is due to the random orientation of pairs of homologous chromosomes in meiosis I. | |
| 10.1.S1 | Drawing diagrams to show chiasmata formed by crossing over. | Diagrams of chiasmata should show sister chromatids still closely aligned, except at the point where crossing over occurred and a chiasma was formed. |

# **Meiosis** is a **reduction division** of the **nucleus** to form **haploid gametes**

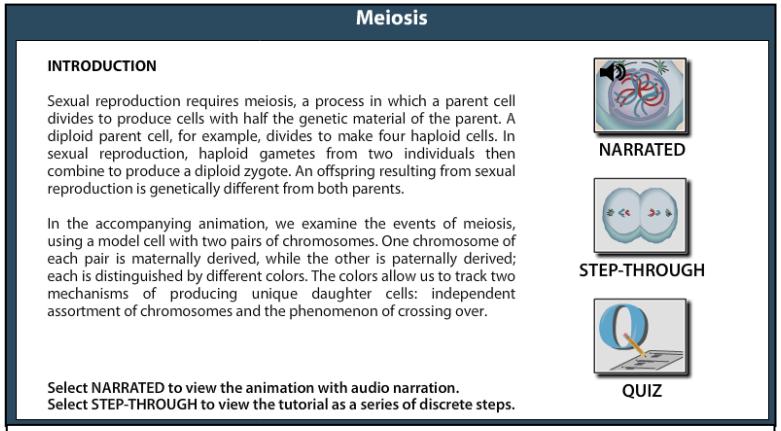
**One diploid (2N)** body **cells** contain a homologous pair of each chromosome (except for sex cells)

**Four haploid (N) gametes** contain one of each chromosome



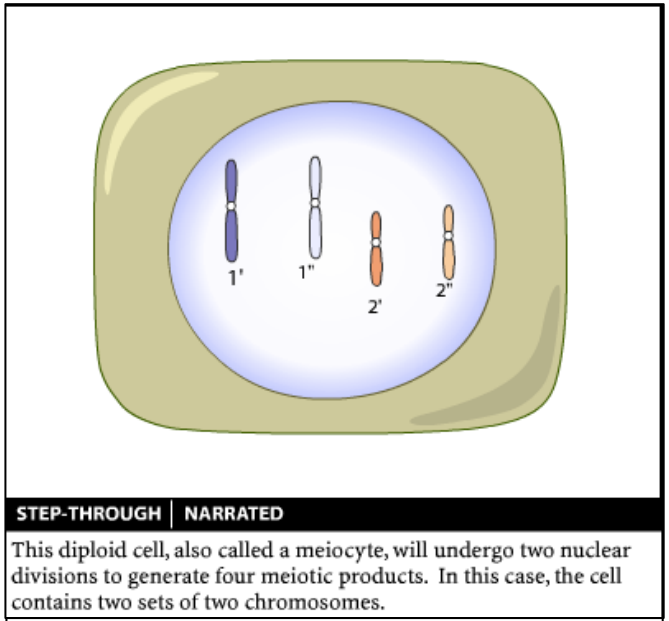

Edited from: https://commons.wikimedia.org/wiki/File:Diagram_of_meiosis.svg

# **Meosis** is a **reduction division** of the **nucleus** to form **haploid gametes**

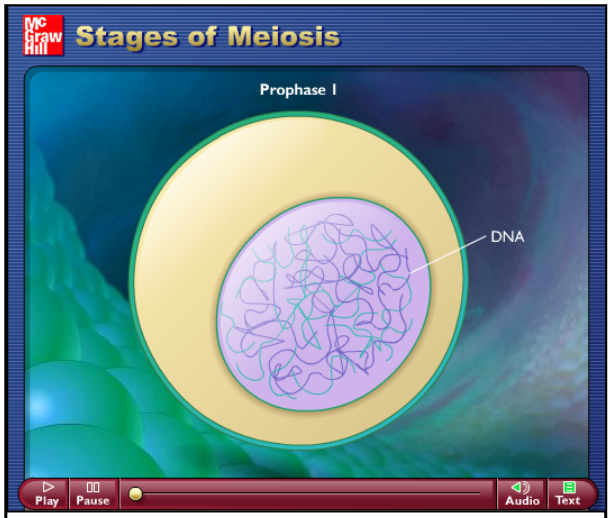



http://www.sumanasinc.com/webcontent/animations/content/meiosis.html

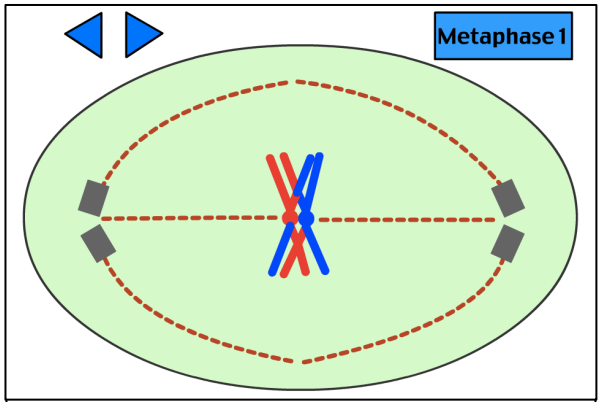
The animations are a great way to visualise the process – watch and take notes.




http://www.biostudio.com/d_%20Meiosis.htm




http://highered.mheducation.com/sites/dl/free/0072437316/120074/bio19.swf




http://www.stolaf.edu/people/giannini/flashanimat/celldivision/meiosis.swf

**Review:** 3.3.U3 DNA is replicated before meiosis so that all chromosomes consist of two sister chromatids.

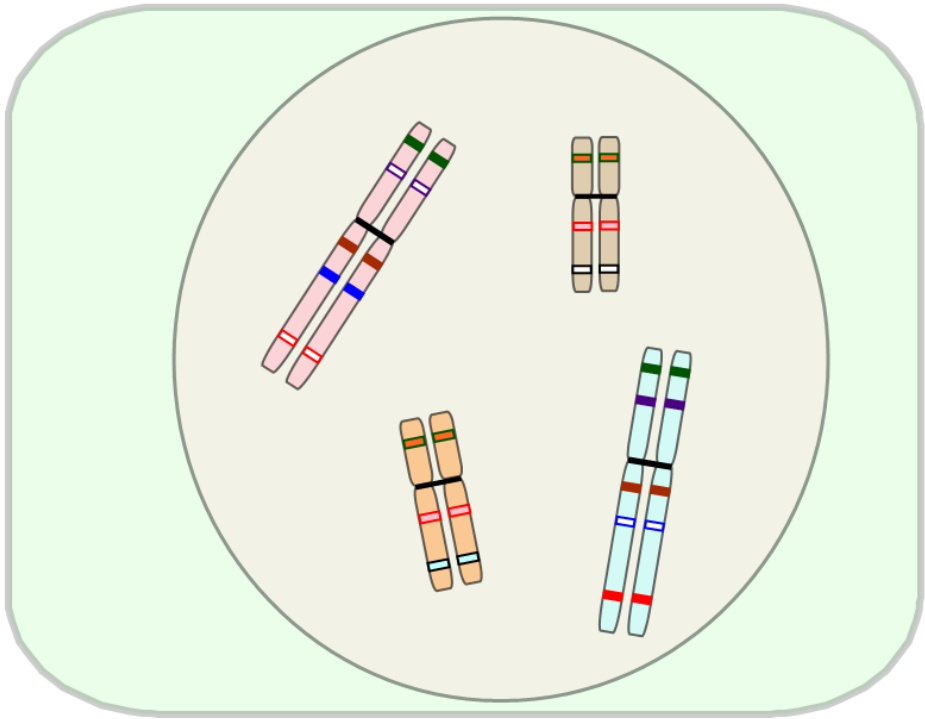
# Interphase

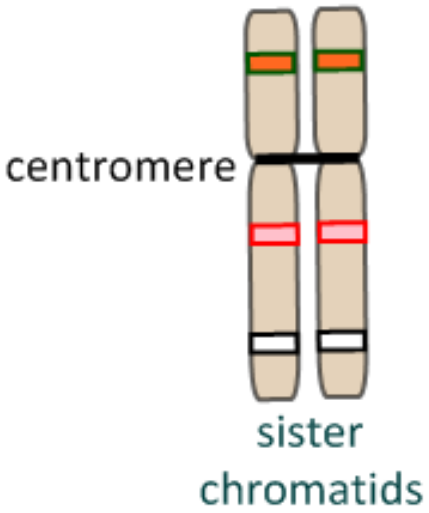
In the S-phase of the interphase before meiosis begins, DNA replication takes place.

Chromosomes are replicated and these copies are attached to each other at the centromere.

The attached chromosome and its copy are known as sister chromatids.

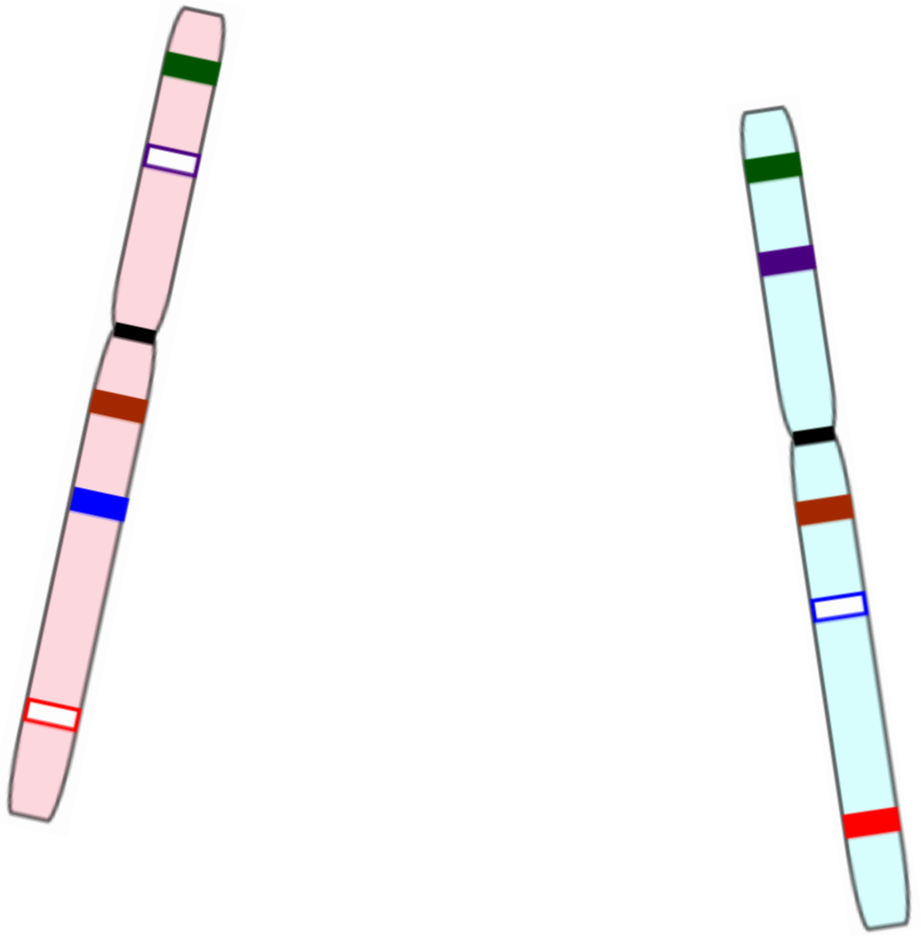
Following S-phase, further growth and preparation take place for meiosis.





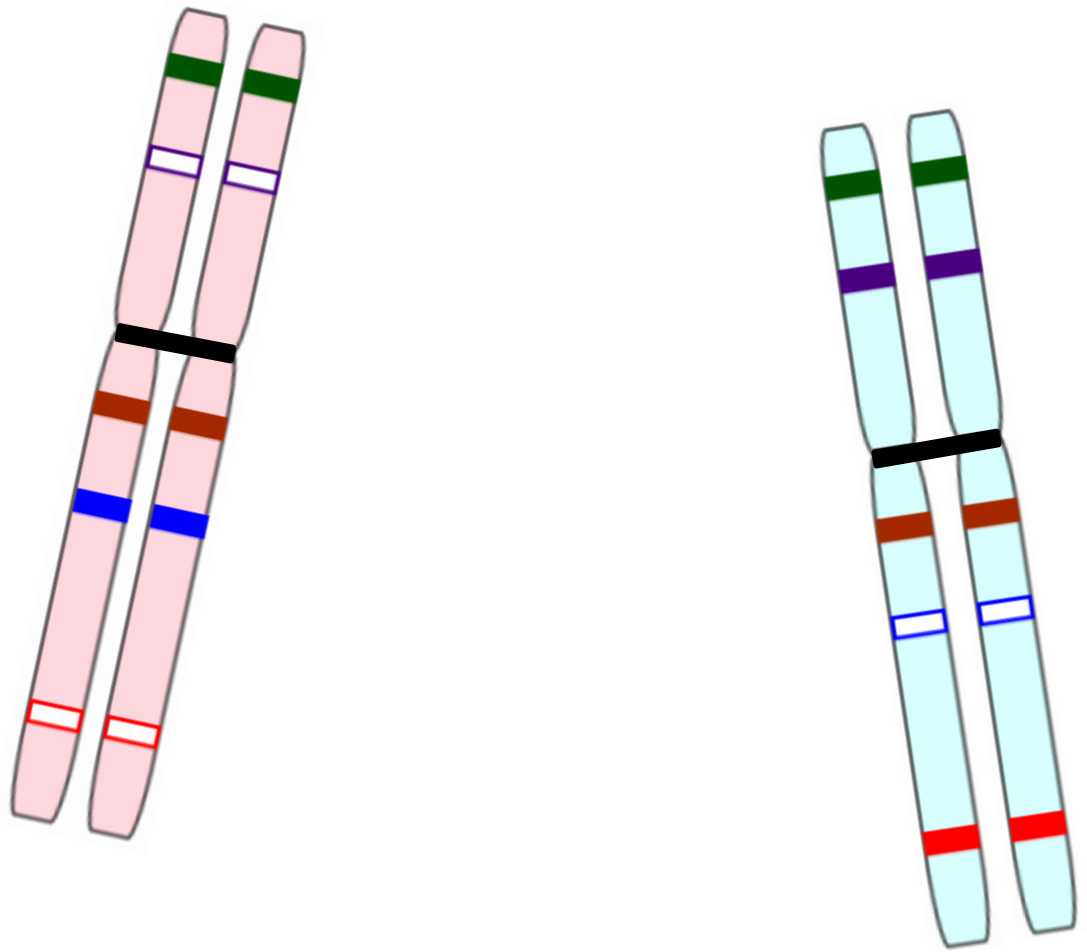
# 10.1.U1 Chromosomes replicate in interphase before meiosis.

**An homologous pair of chromosomes…**



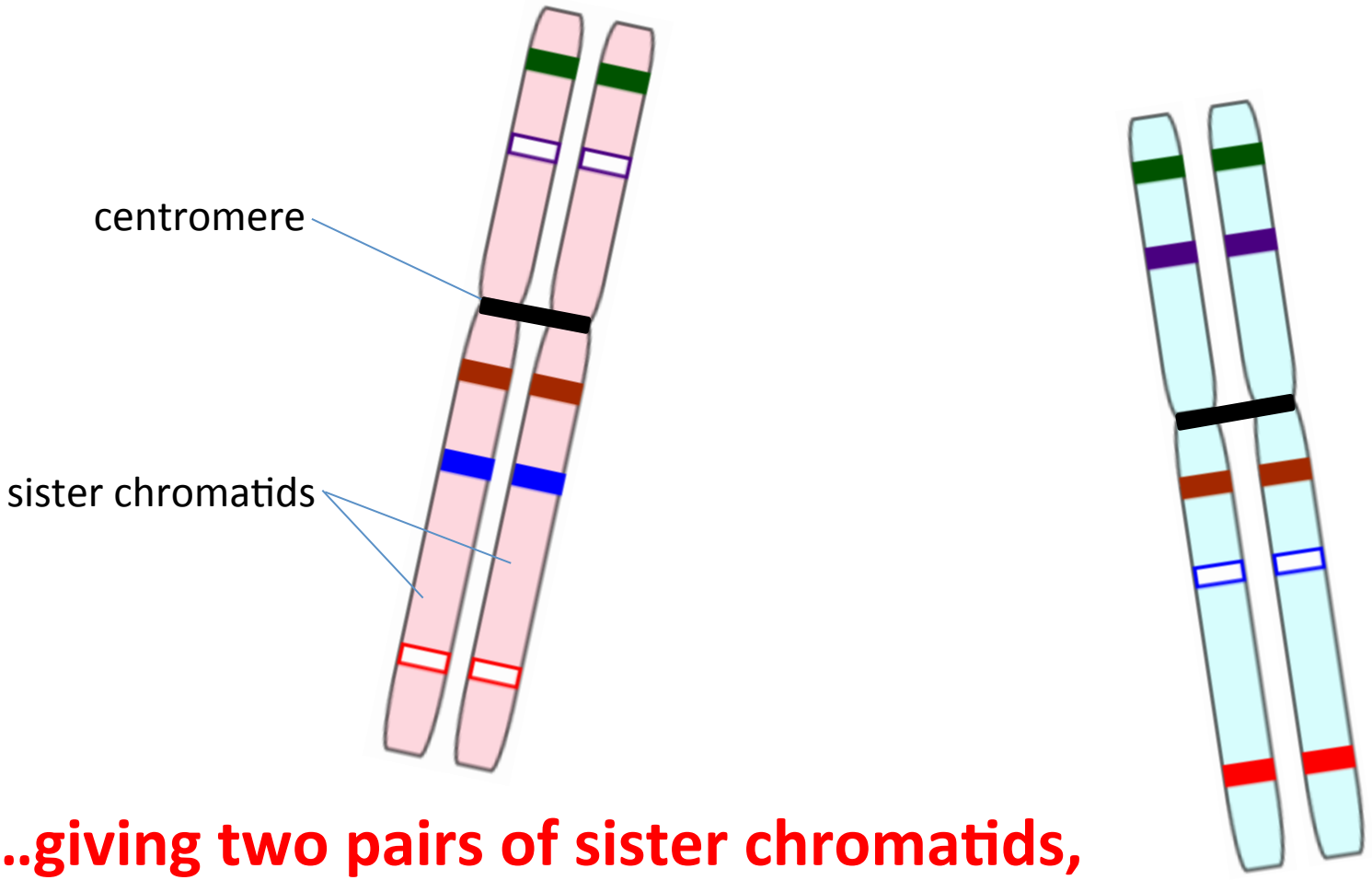
# An homologous pair of chromosomes…

## …replicates during S-phase of interphase…



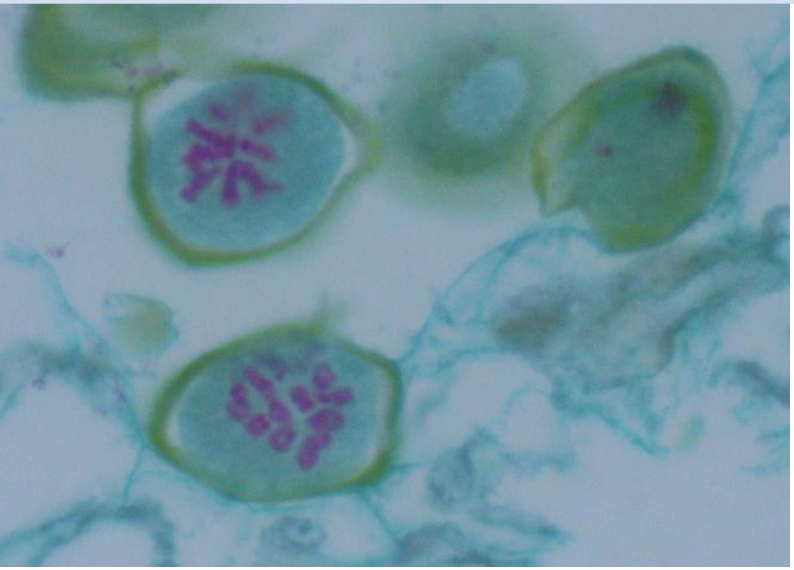
# An homologous pair of chromosomes…

## …replicates during S-phase of interphase…



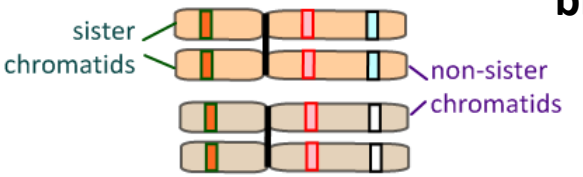

## …giving two pairs of sister chromatids, each joined at the centromere.

**Review:** 3.3.S1 Drawing diagrams to show the stages of meiosis resulting in the formation of four haploid cells. AND 3.3.U4 The early stages of meiosis involve pairing of homologous chromosomes and crossing over followed by condensation.



# Prophase I

The **homologous chromosomes** associate with each other to form **bivalents (**synapsis).

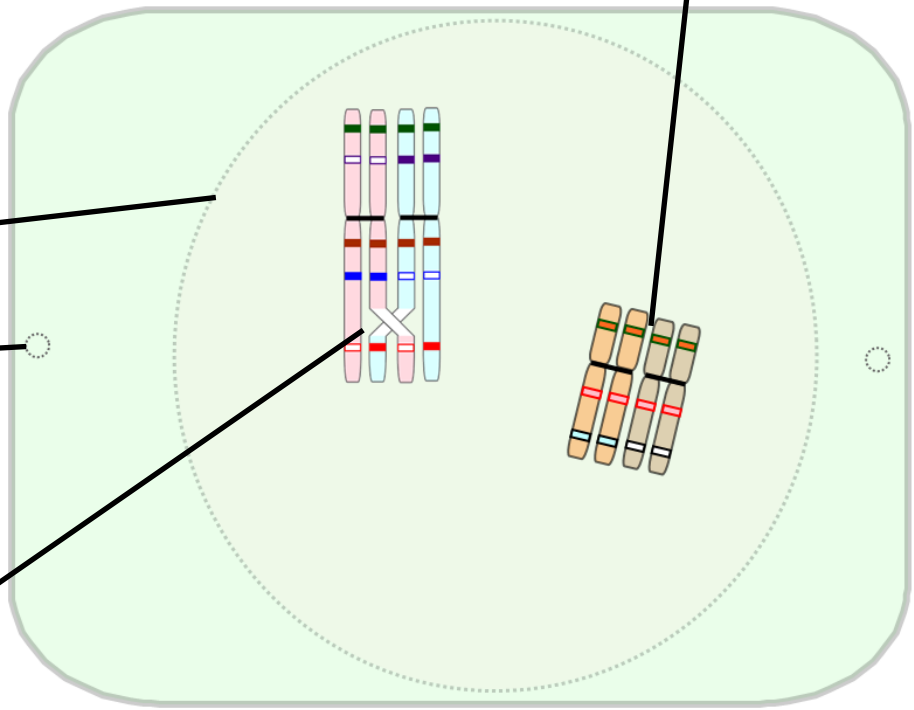



DNA supercoils and chromosomes condense

nuclear membrane dissolves

centrioles migrate to the poles of the cell.

**Crossing-over** between non-sister chromatids can take place. This results in **recombination of alleles** and is a source of genetic variation in gametes.

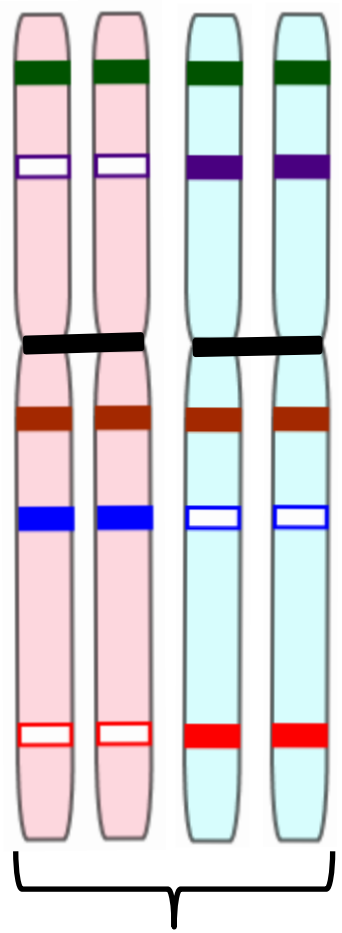


Edited from: http://www.slideshare.net/gurustip/meiosis-ahl

http://www2.sunysuffolk.edu/gambier/micrographs/lateprophase3.htm

10.1.U2 Crossing over is the exchange of DNA material between non-sister homologous chromatids. AND 10.1.U4 Chiasmata formation between non-sister chromatids can result in an exchange of alleles.

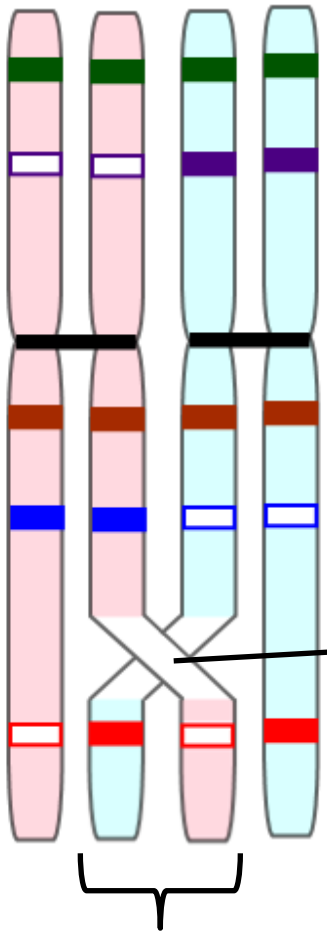
**The homologous pair associates during prophase I, through synapsis…**



**…making a bivalent (or tetrad) .**

10.1.U2 Crossing over is the exchange of DNA material between non-sister homologous chromatids. AND
10.1.U4 Chiasmata formation between non-sister chromatids can result in an exchange of alleles.

# Crossing-over might take place between non-sister chromatids in prophase I…



The location of **crossing-over** between **non-sister chromatids** is called the **chiasma** (pl. **chiasmata**).

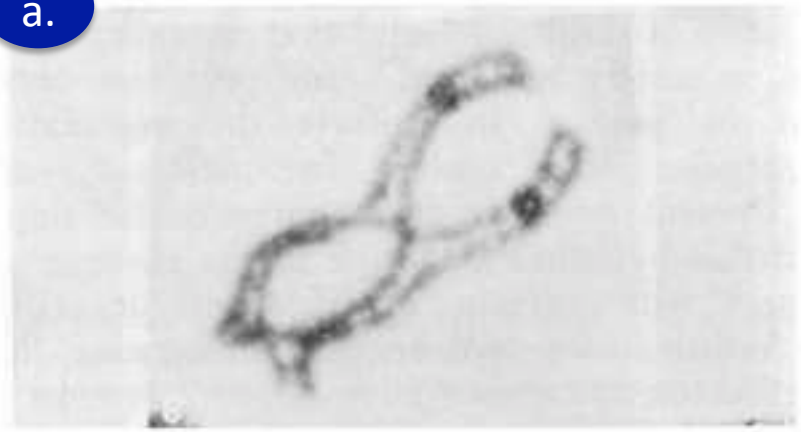
**…leading to recombination of *alleles*.**

# The formation of chiasma is common and is thought to be essential for meiosis

*In humans the average number of chiasmata per bivalent (tetrad) is just over two.*

How many **chiasma** can you identify in the micrographs?

a.



b.

**Chiasma** occur **between** the sister chromatids and therefore should be appear the **central space**.

http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/Chiasmata013.jpg

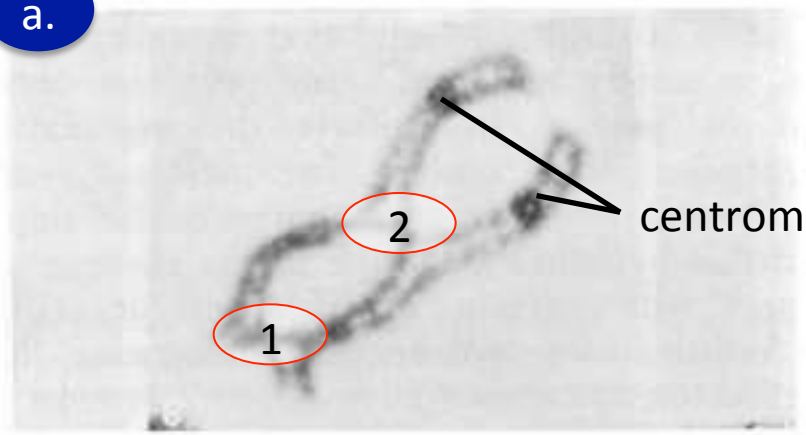
http://nzetc.victoria.ac.nz/etexts/Bio13Tuat01/Bio13Tuat01_063a(h280).jpg

# The formation of chiasma is common and is thought to be essential for meiosis

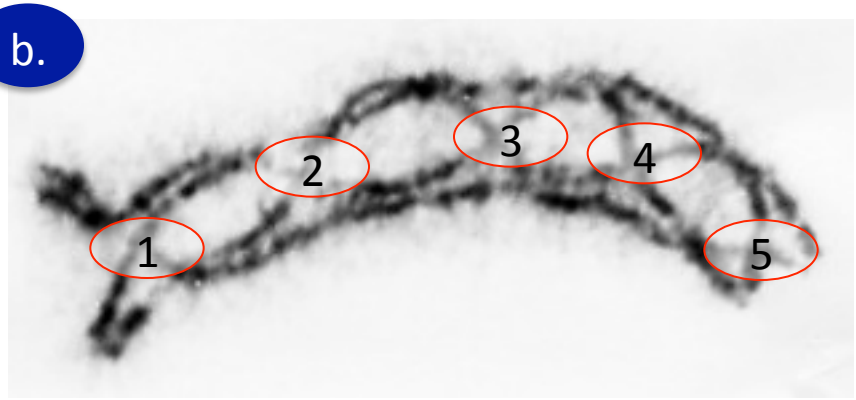
*In humans the average number of chiasmata per bivalent (tetrad) is just over two.*

How many **chiasma** can you identify in the micrographs?

a.




b.




**Chiasma** occur **between** the sister chromatids and therefore should be appear the the **central space**.

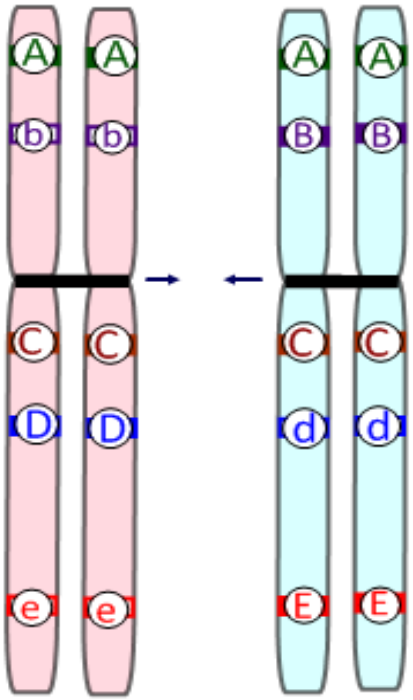
http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/Chiasmata013.jpg

http://nzetc.victoria.ac.nz/etexts/Bio13Tuat01/Bio13Tuat01_063a(h280).jpg

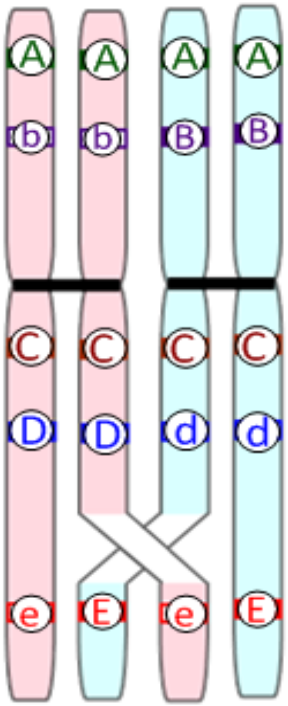
10.1.U3 Crossing over produces new combinations of alleles on the chromosomes of haploid cells.

# Crossing-over

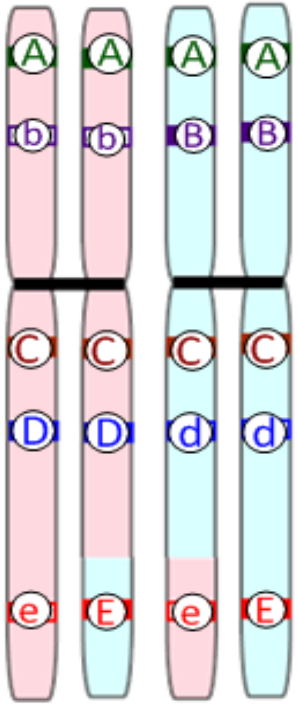
*Increases genetic variation through recombination of linked alleles.*




**Synapsis**
Homologous chromosomes associate



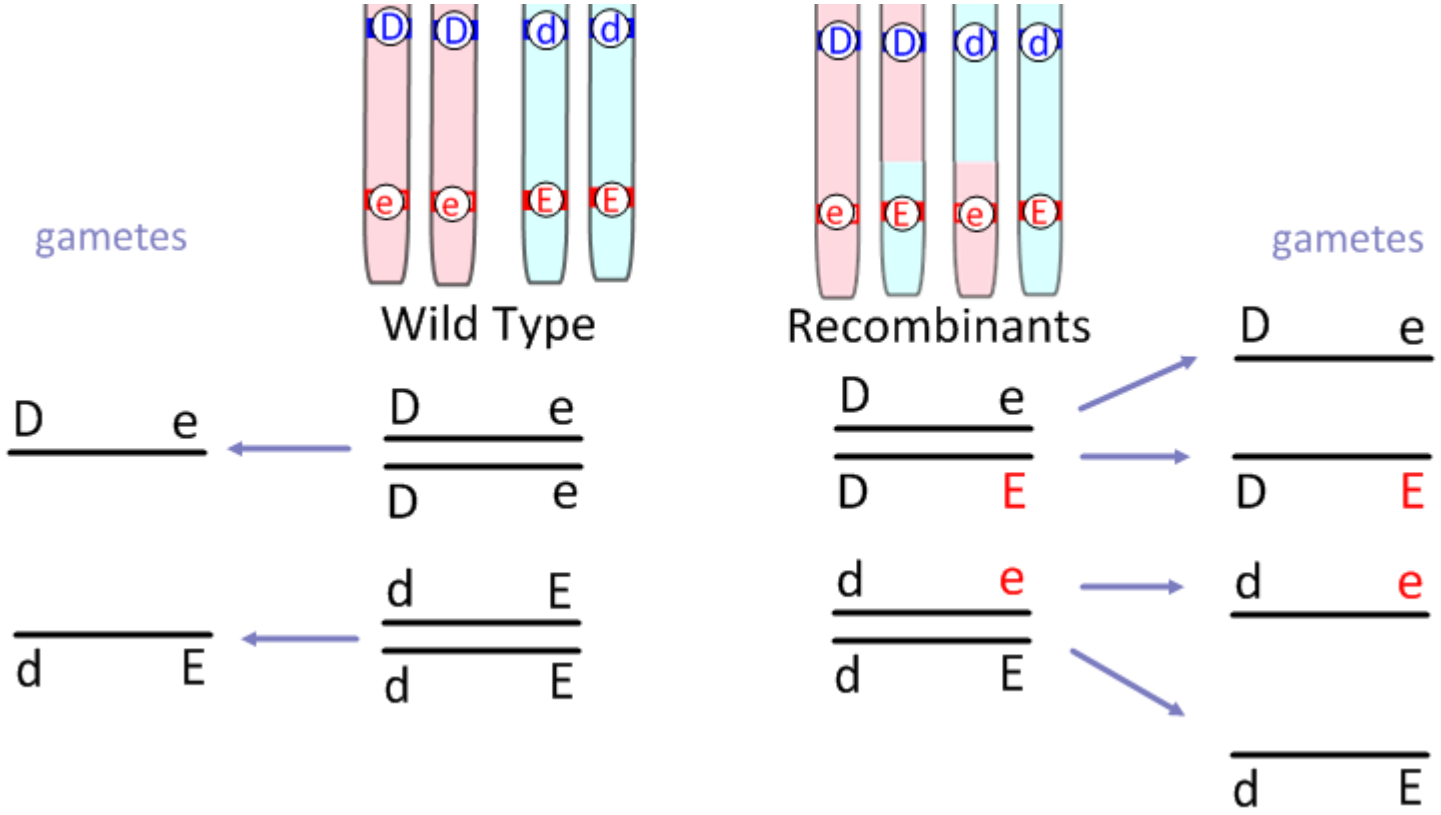

**Chiasma Formation**
Neighboring non-sister chromatids are cut at the same point.
A Holliday junction forms as the DNA of the cut sections attach to the open end of the opposite non-sister chromatid.




**Recombination**
As a result, alleles are swapped between non-sister chromatids.

# Crossing-Over

*Increases genetic variation through recombination of linked alleles.*




**Crossing over** leads to more **variation in gametes**.

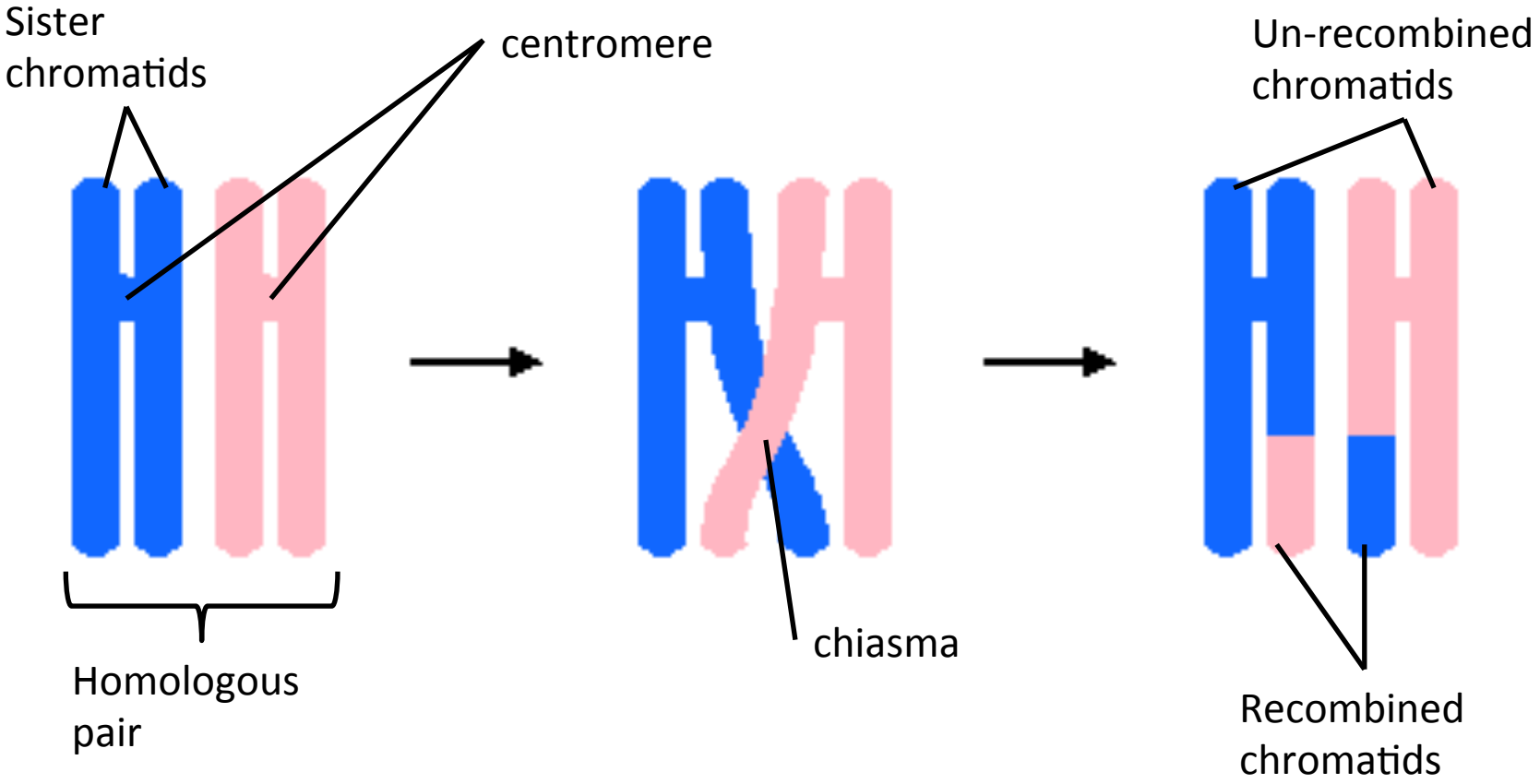
This is the standard notation for writing genotypes of alleles on linked genes (more of this later when we study 10.2 Inheritance AHL)

Edited from: http://www.slideshare.net/gurustip/meiosis-ahl

# 10.1.S1 Drawing diagrams to show chiasmata formed by crossing over.

# Crossing-Over

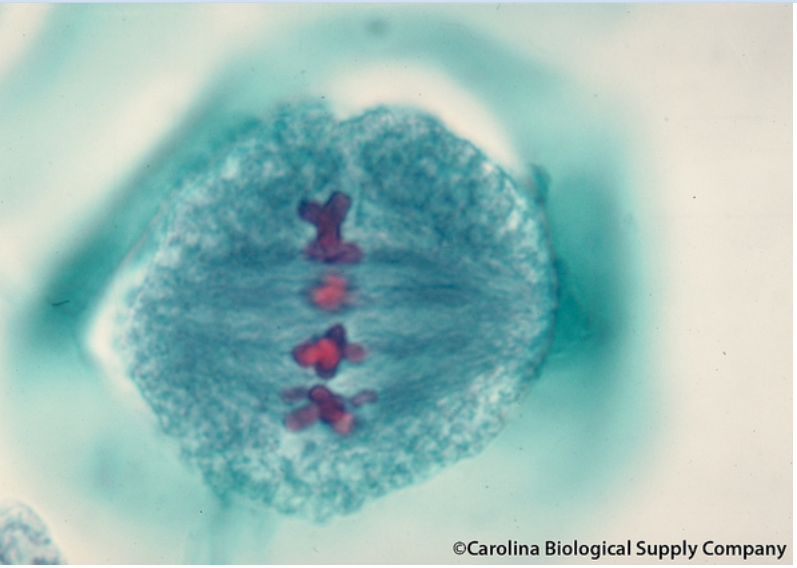
*Drawing clear diagrams helps when communicating with others*




Key points when drawing chiasmata:

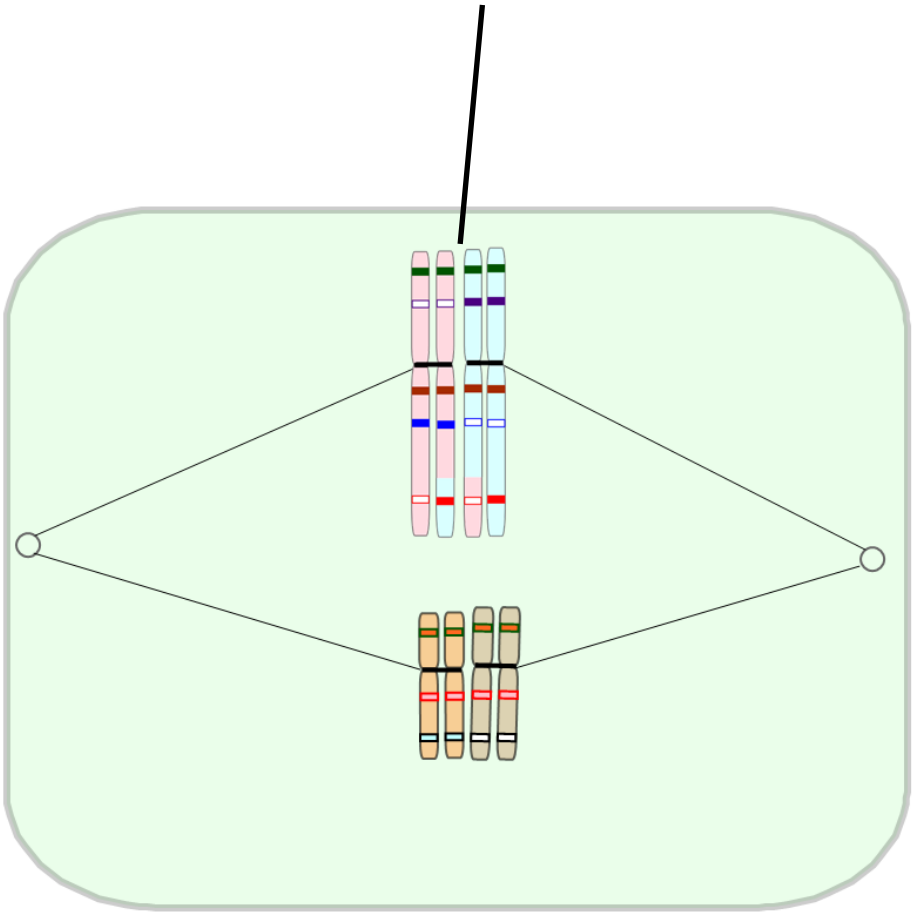
- Use colour of shading to indicate the each of the sister chromatids
- Remember the homologous chromosomes are in synapsis – before and after crossing over the chromosomes should be shown close together.

**Review:** 3.3.S1 Drawing diagrams to show the stages of meiosis resulting in the formation of four haploid cells. AND 3.3.U5 Orientation of pairs of homologous chromosomes prior to separation is random.




# Metaphase I

The **bivalents line up** at the **equator**.



**Random orientation** occurs - each bivalent aligns independently and hence the daughter nuclei get a different mix of chromosomes.

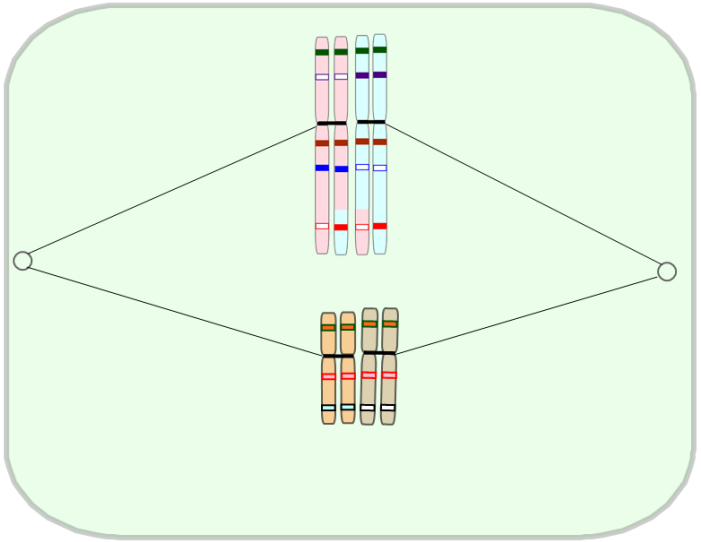
This is a significant source of genetic variation: there are $2^n$ possible orientations in metaphase I and II. That is $2^{23}$ in humans – or **8,388,068** different combinations in gametes!

Edited from: http://www.slideshare.net/gurustip/meiosis-ahl

courtesy of: http://www.flickr.com/carolinabio

10.1.U7 Independent assortment of genes is due to the random orientation of pairs of homologous chromosomes in meiosis I.

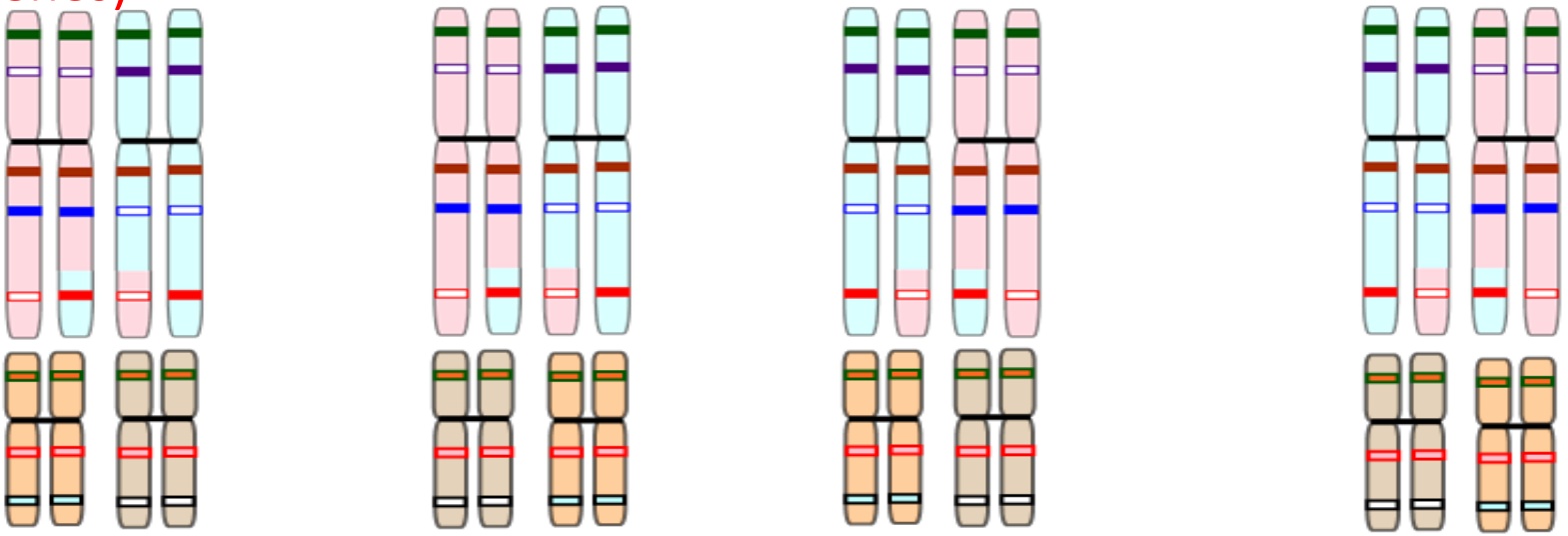
# Metaphase I



Alleles have a 50 percent chance of moving to a particular pole.

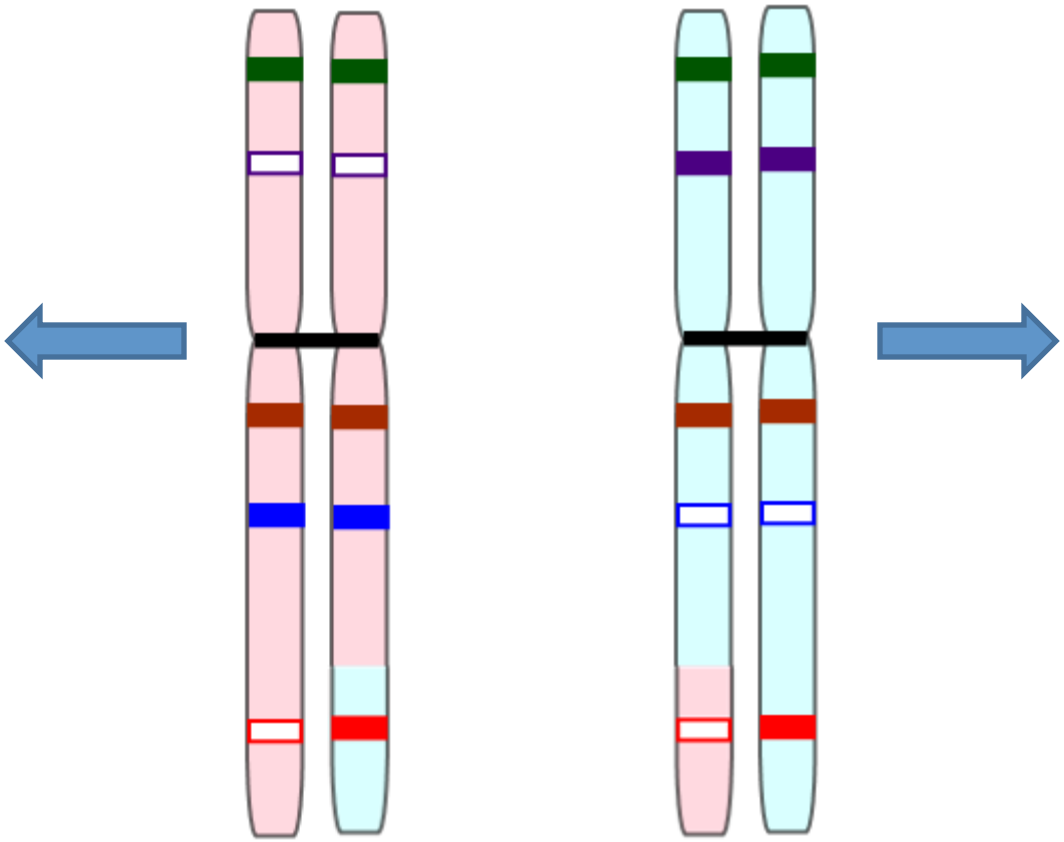
The direction in which one bivalent aligns does not affect the alignment of other bivalents.

Therefore different allele combinations should always be equally possible (if the gene loci are on different chromosomes – this does not hold for linked genes)



Edited from: http://www.slideshare.net/gurustip/meiosis-ahl

**In anaphase I, the homologous pair is separated but the sister chromatids remain attached.**



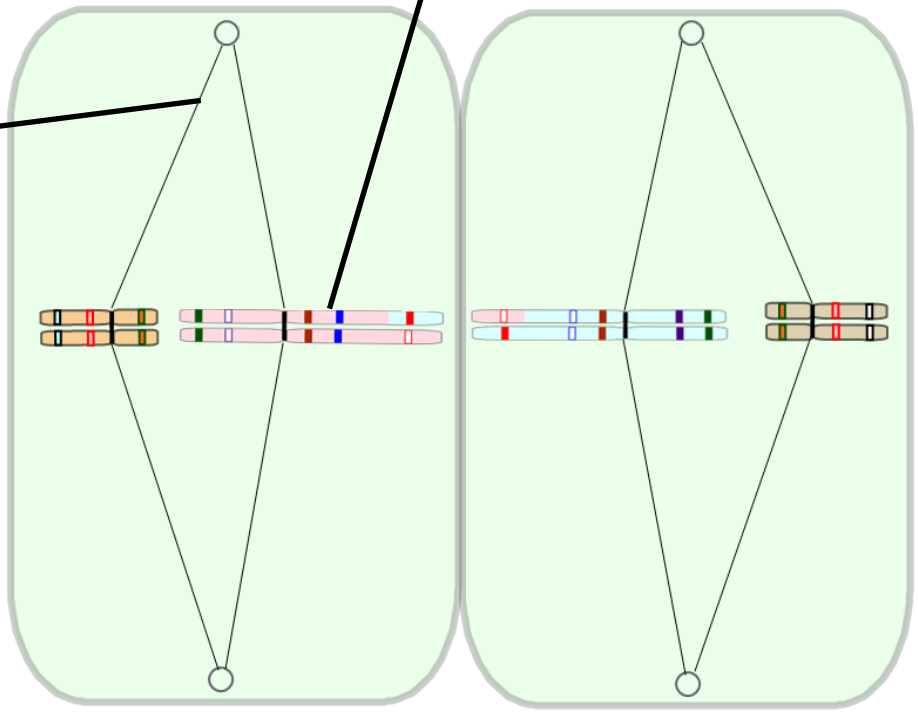
**This is the reduction division.**

**Review:** 3.3.S1 Drawing diagrams to show the stages of meiosis resulting in the formation of four haploid cells.


# Metaphase II

Pairs of sister chromatids align at the equator.

Spindle fibres form and attach at the centromeres.

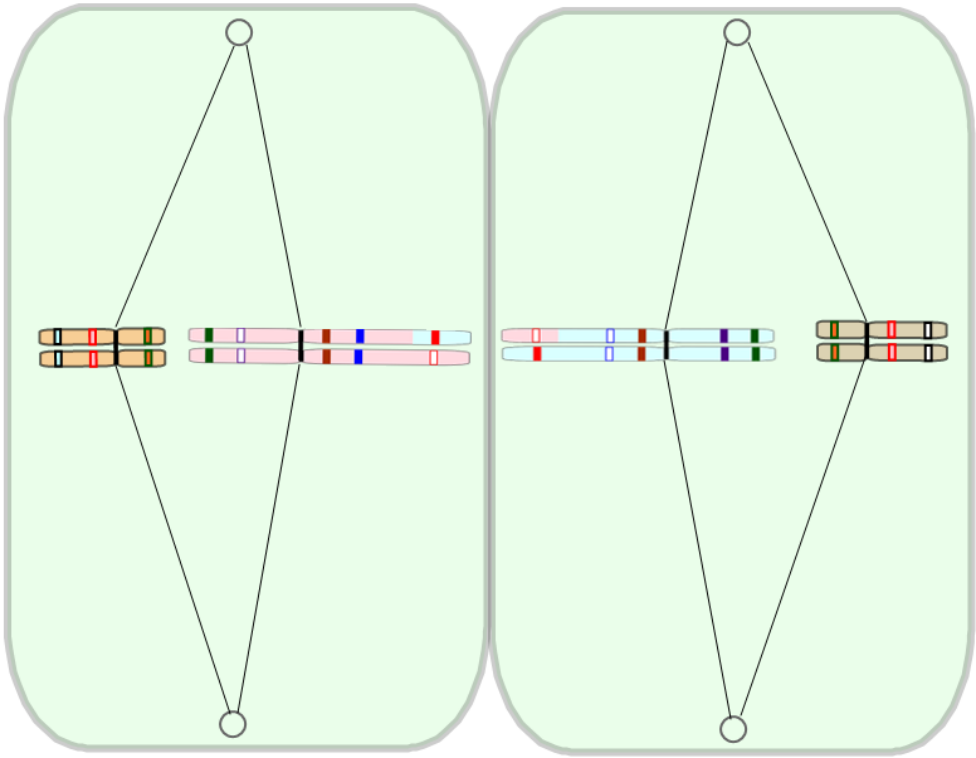


Edited from: http://www.slideshare.net/gurustip/meiosis-ahl

courtesy of: http://www.flickr.com/carolinabio

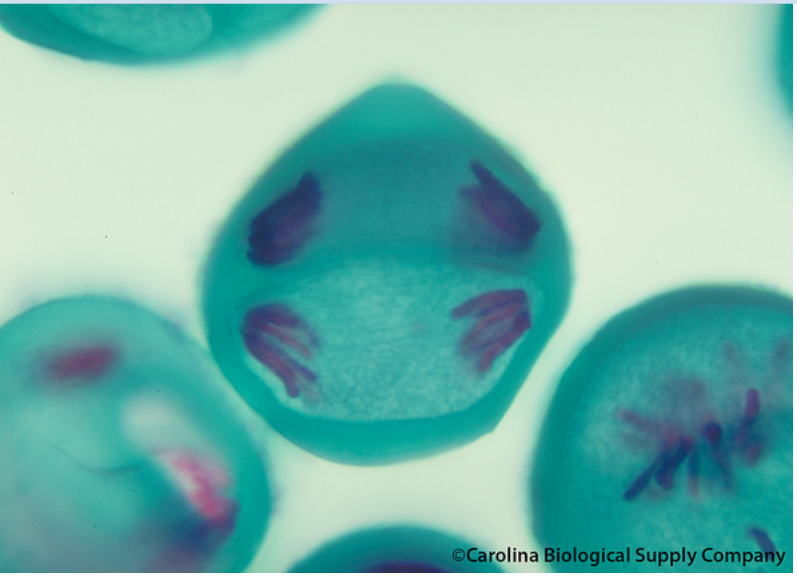
# Metaphase II

Pairs of sister chromatids align at the equator. Spindle fibres form and attach at the centromeres.



Random orientation again contributes to variation in the gametes, though not to such an extent as in metaphase I.

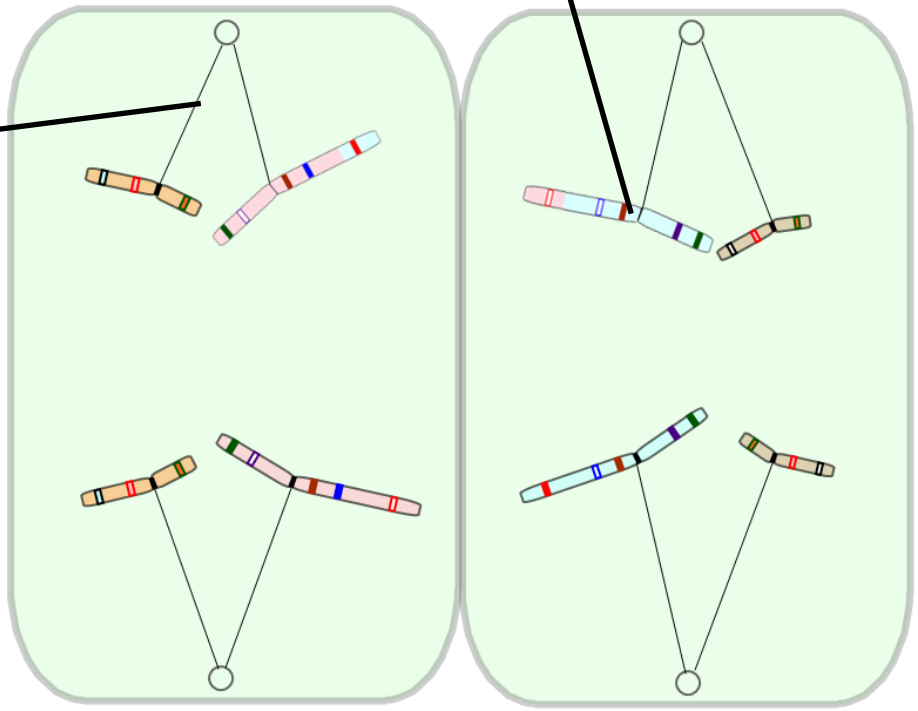
This is because there is only a difference between chromatids where crossing-over has taken place.




# Anaphase II

The sister chromatids are separated. The **chromatids** (now called chromosomes are **pulled** to opposing **poles**.

Spindle fibres contract and the centromeres are split.

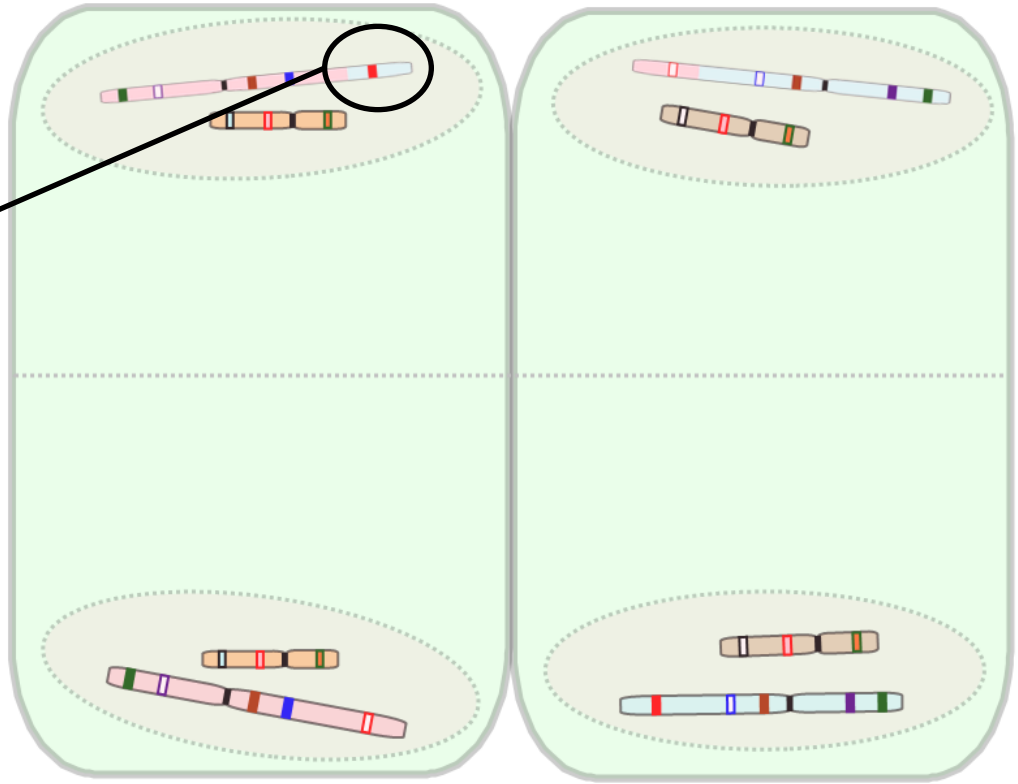


Edited from: http://www.slideshare.net/gurustip/meiosis-ahl

courtesy of: http://www.flickr.com/carolinabio

# Telophase II

*n.b. due to crossing over each of the four new nuclei is likely to be genetically different.*



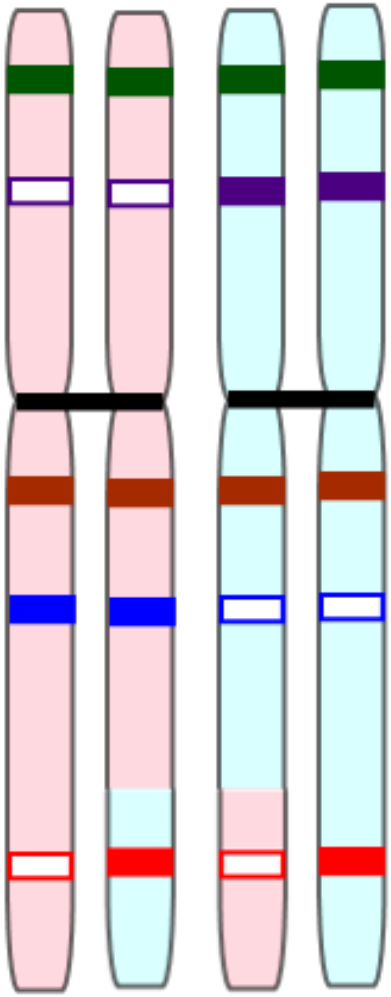
**New haploid nuclei** are formed.

Cytokinesis begins, splitting the cells.

The end result of meiosis is **four haploid gamete cells**.

Fertilization of these haploid gametes will produce a diploid zygote.

# Check your language. This image shows…



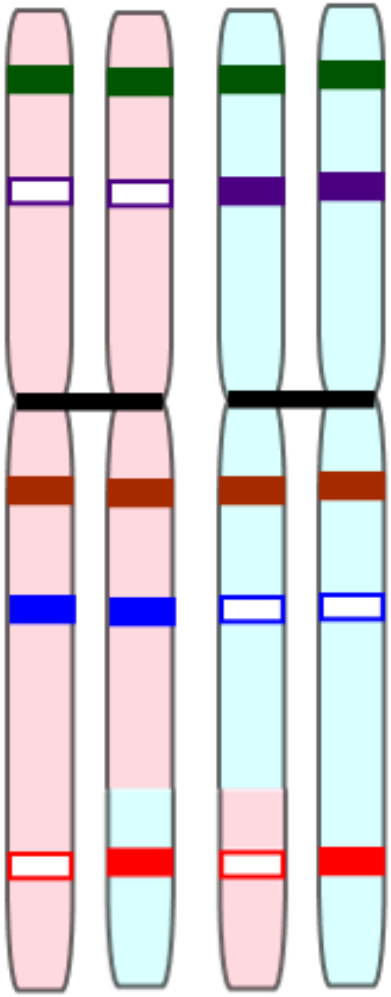
A. Four separate chromosomes.

B. A bivalent.

C. One pair of sister chromatids.

D. Non-disjunction.

# Check your language. This image shows…



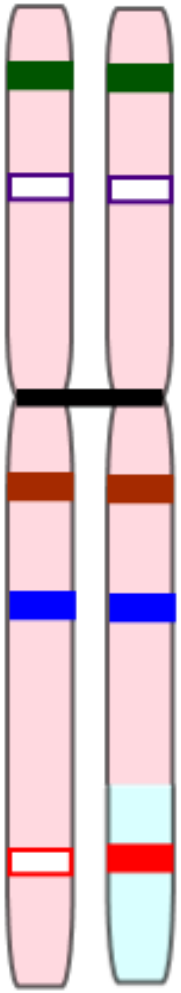
A. Four separate chromosomes.

B. A bivalent.

C. One pair of sister chromatids.

D. Non-disjunction.

# Check your language. This image shows…



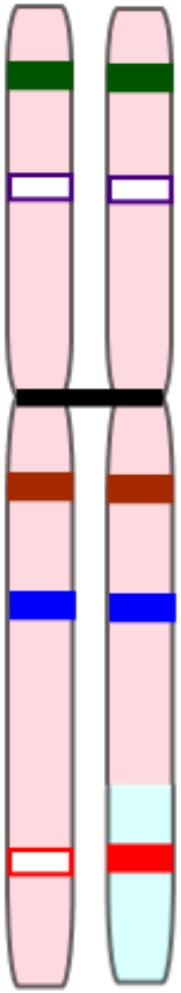
A. Two separate chromosomes.

B. A bivalent.

C. One pair of sister chromatids.

D. Crossing-over.

# Check your language. This image shows…



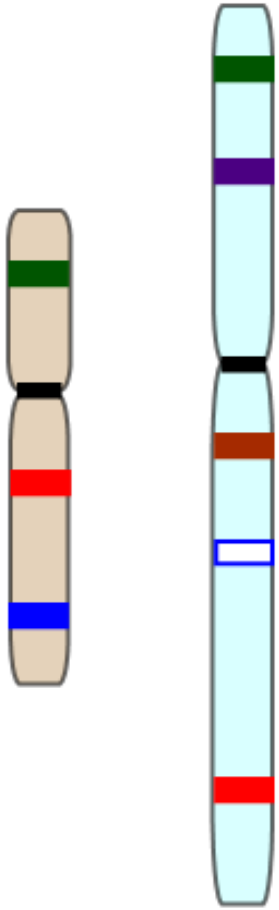
A. Two separate chromosomes.

B. A bivalent.

C. One pair of sister chromatids.

D. Crossing-over.

# Check your language. This image shows…



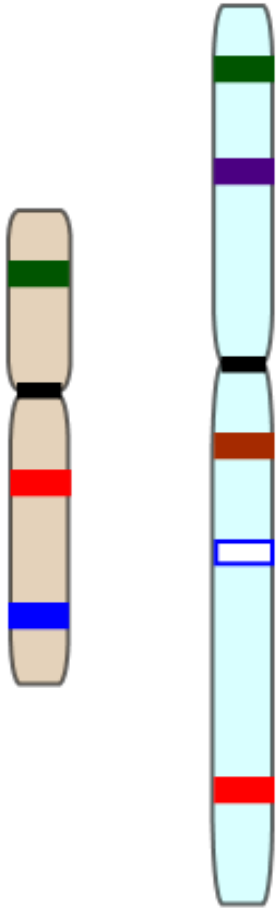
A. Two separate chromosomes.

B. A bivalent.

C. One pair of sister chromatids.

D. Homologous chromosomes.

# Check your language. This image shows…



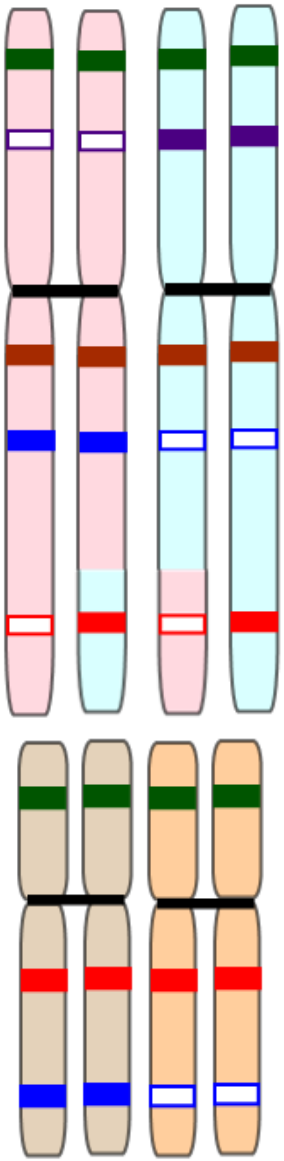
A. Two separate chromosomes.

B. A bivalent.

C. One pair of sister chromatids.

D. Homologous chromosomes.

# Check your language. This image shows…



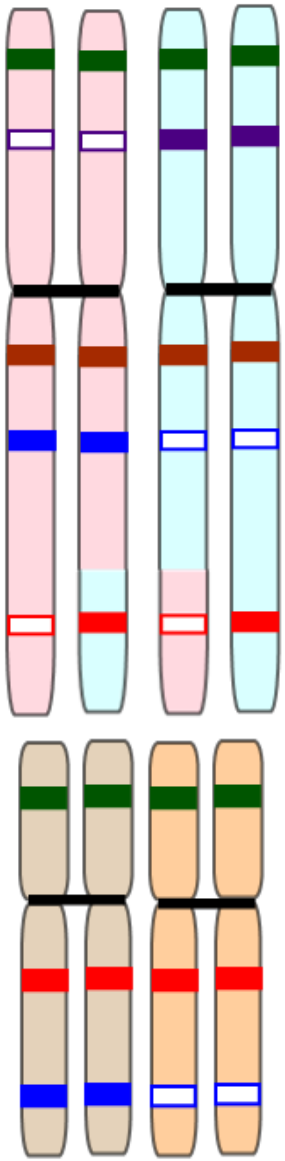
A. 8 separate chromosomes.

B. Two bivalents.

C. Two pairs of sister chromatids.

D. Two homologous chromosomes.

# Check your language. This image shows…



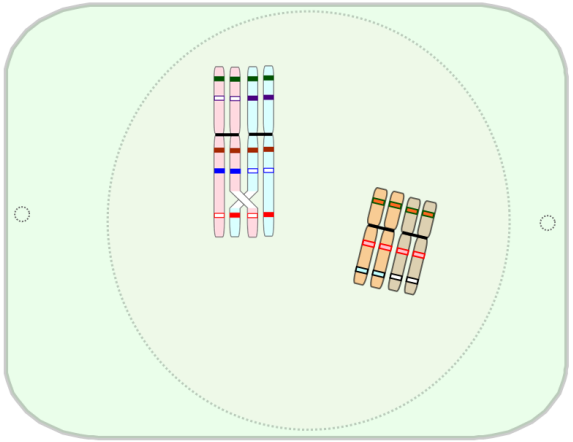
A. 8 separate chromosomes.

B. Two bivalents.

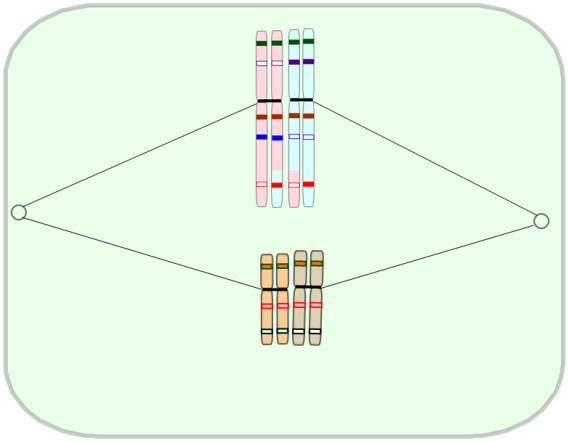
C. Two pairs of sister chromatids.

D. Two homologous chromosomes.

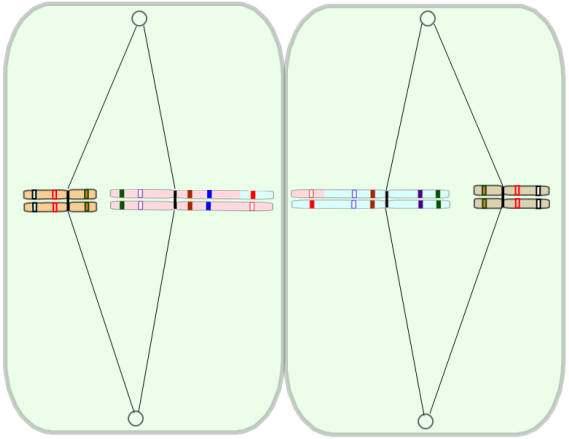
# Prophase I



# Metaphase I



# Metaphase II



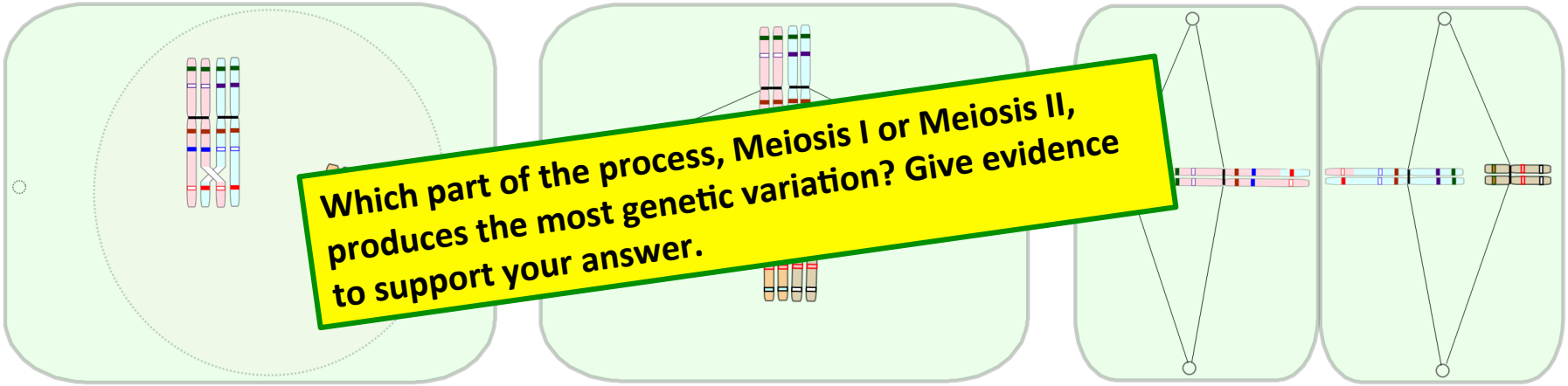
**Crossing-over** between non-sister chromatids results in **recombination of alleles**

**Random orientation** of the homologous chromosomes means there are $2^n$ possible orientations in metaphase I and II. That is $2^{23}$ in humans – or **8,388,068** different combinations in gametes!

Because both **crossing-over** and **random orientation** occur during meiosis the result is is effectively infinite **genetic variation** in the haploid gamete.

*n.b. for a new organism to arise sexually meiosis occurs in both parents further increasing the genetic variation*

# Prophase I Metaphase I Metaphase II




**Crossing-over** between non-sister chromatids results in **recombination of alleles**

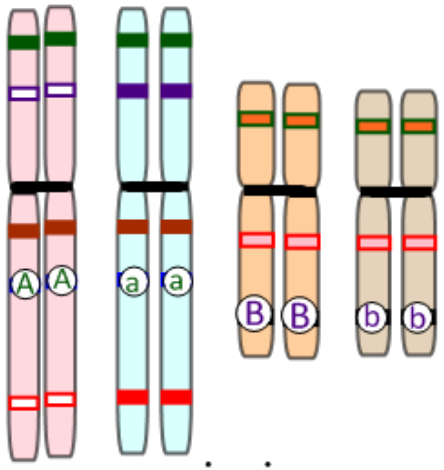
**Random orientation** of the homologous chromosomes means there are $2^n$ possible orientations in metaphase I and II. That is $2^{23}$ in humans – or **8,388,068** different combinations in gametes!

Because both **crossing-over** and **random orientation** occur during meiosis the result is is effectively infinite **genetic variation** in the haploid gamete.

# Mendel's Law of Independent Assortment

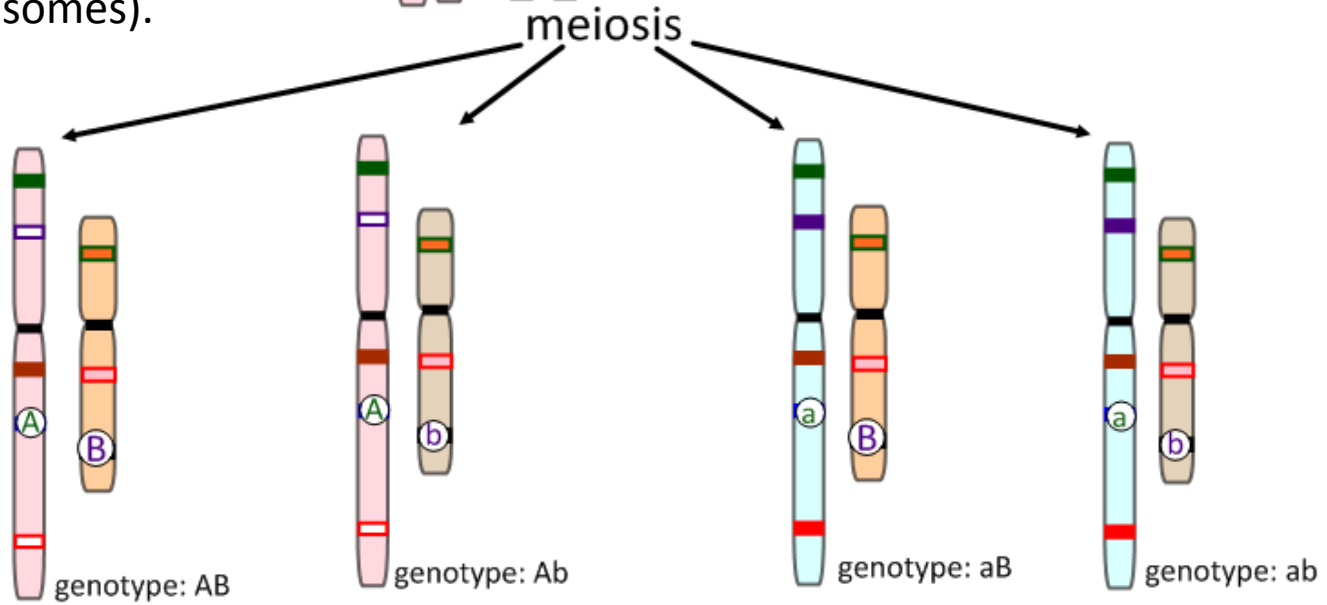
*"The presence of an allele of one of the genes in a gamete has no influence over which allele of another gene is pr*

This only holds true for **unlinked genes** (genes on different chromosomes).




A and B are different genes on different chromosomes.

A is dominant over a.
B is dominant over b.

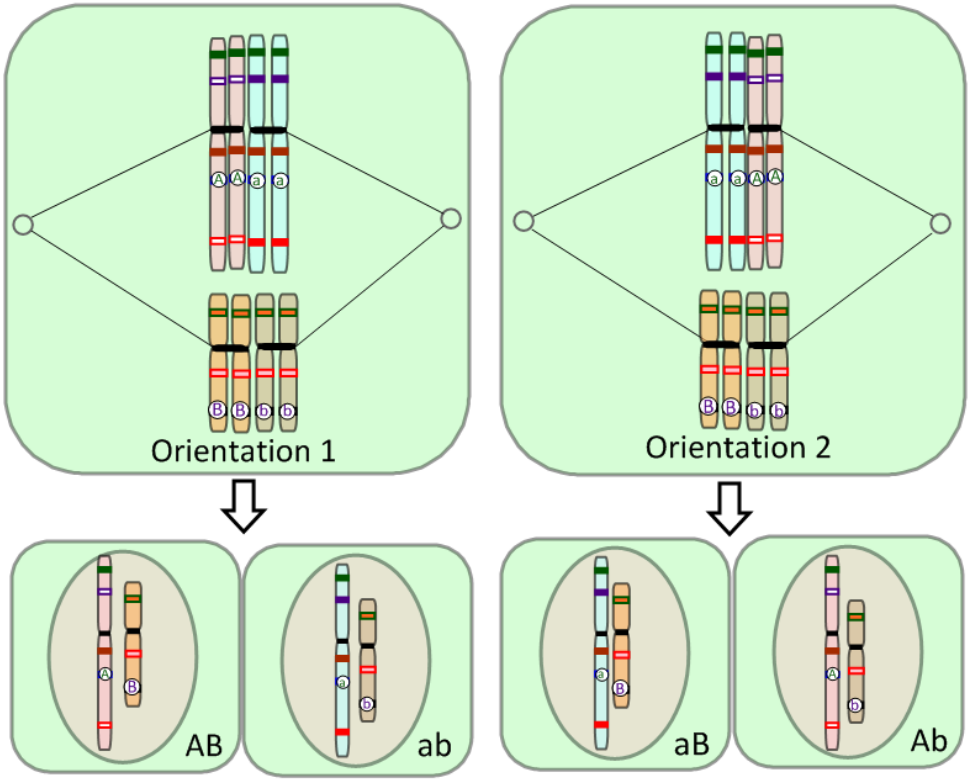


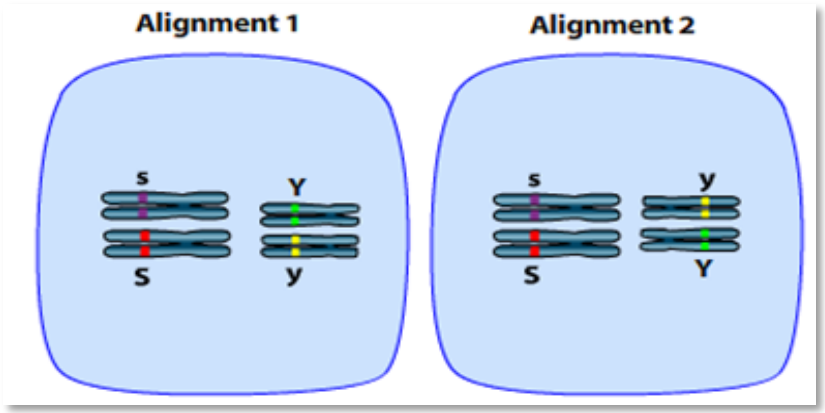
# Random Orientation vs Independent Assortment

*"The presence of an allele of one of the genes in a gamete has no influence over which allele of another gene is present."*

**Random Orientation** refers to the behavior of homologous pairs of chromosomes (metaphase I) or pairs of sister chromatids (metaphase II) **in meiosis**.

**Independent assortment** refers to the behaviour of alleles of unlinked genes **as a result of gamete production** (meiosis).




Due to **random orientation of the chromosomes** in metaphase I, the **alleles** of these unlinked genes **have become independently assorted** into the gametes.

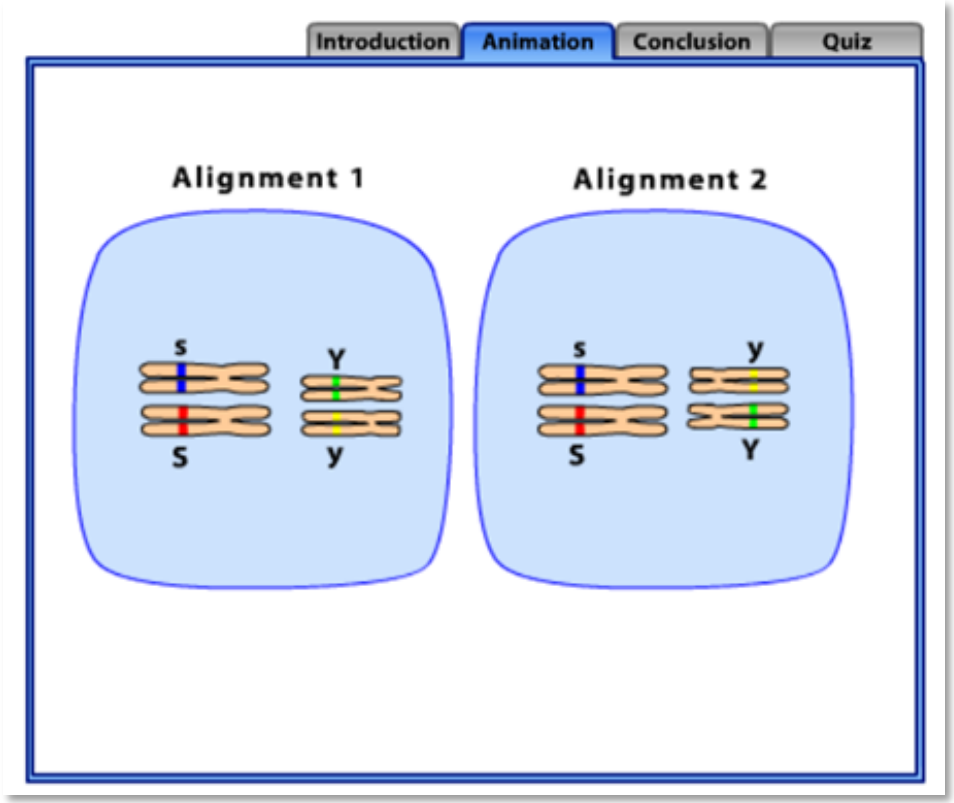
**Animation from Sumanas**:
http://www.sumanasinc.com/webcontent/animations/content/independentassortment.html

# Mendel and Meiosis

*"The presence of an allele of one of the genes in a gamete has no influence over which allele of another gene is present."*

Mendel deduced that characteristics were determined by the interaction between pairs of alleles long before the details of meiosis were known.

Where Mendel states that *pairs of alleles of a gene separate independently during gamete production*, we can now attribute this to **random orientation** of chromosomes




Mendel made this deduction when working with pea plants. He investigated two separate traits (color and shape) and performed many test crosses, recording the ratios of phenotypes produced in subsequent generations.

It was rather fortunate that these two traits happened to be on separate chromosomes (unlinked genes)! Remember back then he did not know about the contents of the nucleus. Chromosomes and DNA were yet to be discovered.

We will use his work as an example of dihybrid crosses in the next section.

**Animation from Sumanas**: http://www.sumanasinc.com/webcontent/animations/content/independentassortment.html

Nature of Science: Making careful observations—careful observation and record keeping turned up anomalous data that Mendel's law of independent assortment could not account for. Thomas Hunt Morgan developed the notion of linked genes to account for the anomalies. (1.8)

Morgan's experiments (1909 - 1914) with fruit flies produced results that could not be explained by Mendel's work on heredity as it stood.

Thomas Hunt Morgan developed the idea of sex-linked genes

Hi, I'm Thomas Hunt Morgan. In 1904, I started the "Fly" lab at Columbia University to study genetic variations. Many of the important discoveries of genetics and chromosomal inheritance came out of my lab through research using fruit flies.

https://www.dnalc.org/view/15005-Thomas-Hunt-Morgan.html

The 'anomalous' data was repeated and found to be predictable. The experiments lead Morgan and his colleagues to revise Mendelian heredity (1915) to include certain key tenets:

- Discrete pairs of factors are located on chromosomes (later to be called genes)
- Certain characteristics are sex-linked
- Other characteristics are also sometimes associated

https://geneticsandevolutionch10.files.wordpress.com/2015/01/kbtnk9dz-13672096431.jpg?w=672&h=327

Columbia University Fly Room

http://www.nature.com/scitable/content/ne0000/ne0000/ne0000/ne0000/122977784/1_2.jpg

# Bibliography / Acknowledgments

BioNinja

*Your one-stop biology resource*



[Bob Smullen]