A. OVERVIEW OF MEIOSIS

- **Cell division** that produces **four haploid cells** that are **genetically different**.
- Produces **gametes** (sex cells)
- Has **two** divisions.
- Has **two** main **jobs**:

1. **Produces haploid (sex) cells that contain half the normal number of chromosomes**.

   This ensures that the correct **diploid number** is **restored** at **fertilisation**.

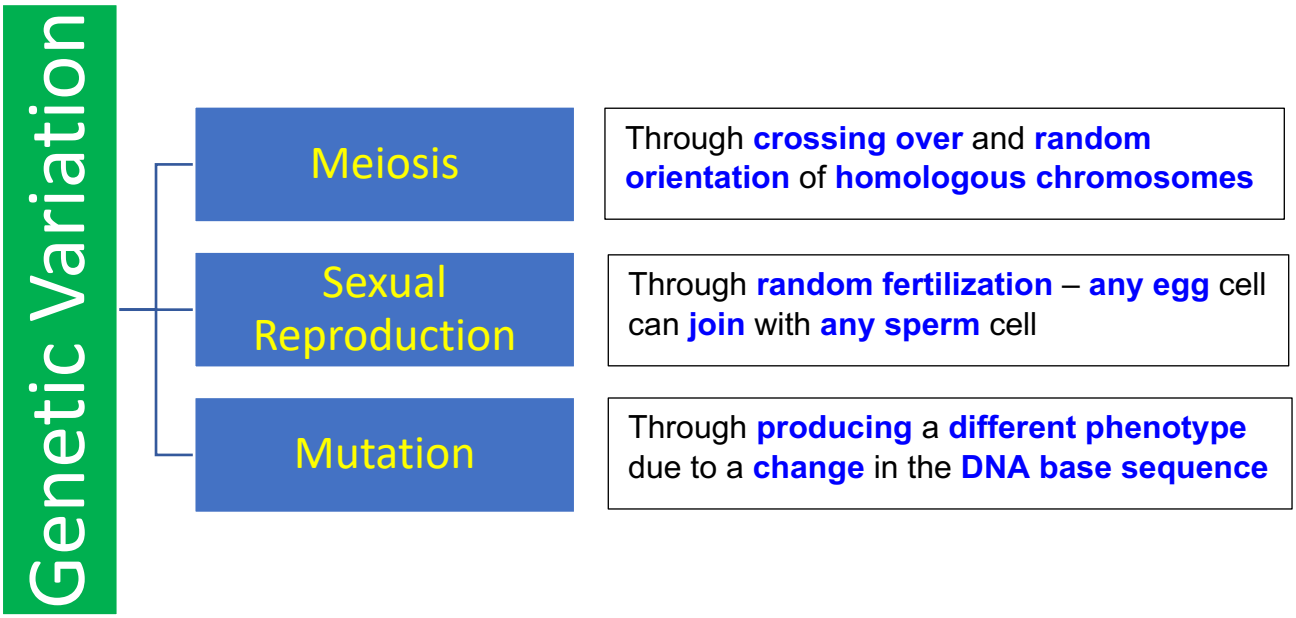
   Otherwise, **each generation** would have **twice as many chromosomes** as the **previous one**.

2. **Increases genetic variation**

   Produces **genetically different** cells.

   Through **crossing over** and **random orientation** of **homologous chromosomes**

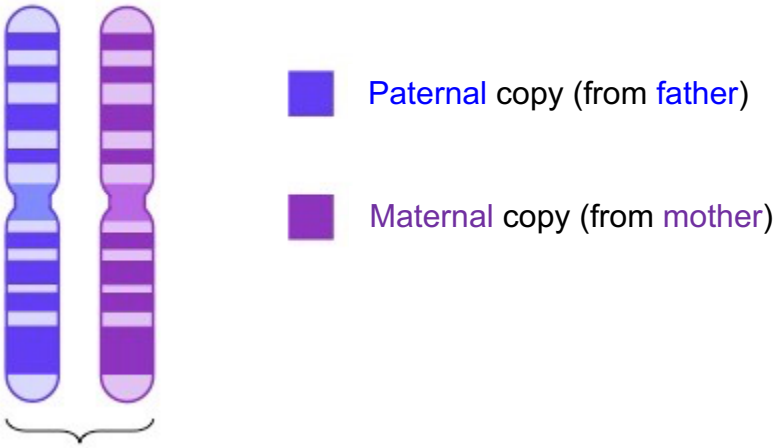
Remember though, that **meiosis** is **one** of **three** methods that **increase genetic variation**:



B. A RECAP ON HOMOLOGOUS CHROMOSOMES

What they are

Here is one pair of homologous chromosomes:



Homologous pair

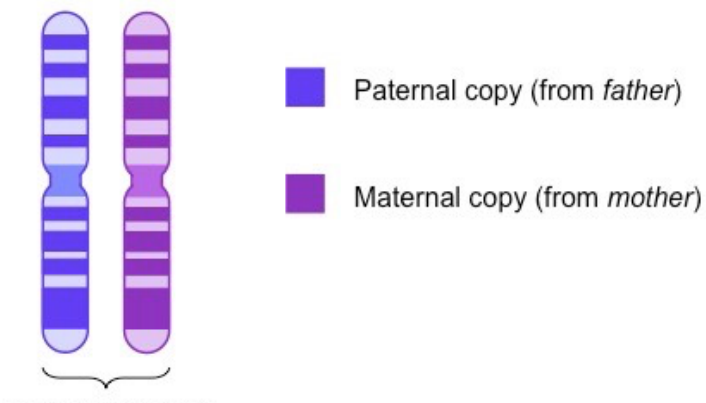
- They are the **same shape** and **size**
- They carry the **same genes** in the **same sequence**
- They carry **different alleles**
- In each pair, **one** chromosome is from **mum** and the **other** is from **dad**

However, in text books, chromosomes look like the letter '**X**', with a **circle** at the centre.

Why is this?

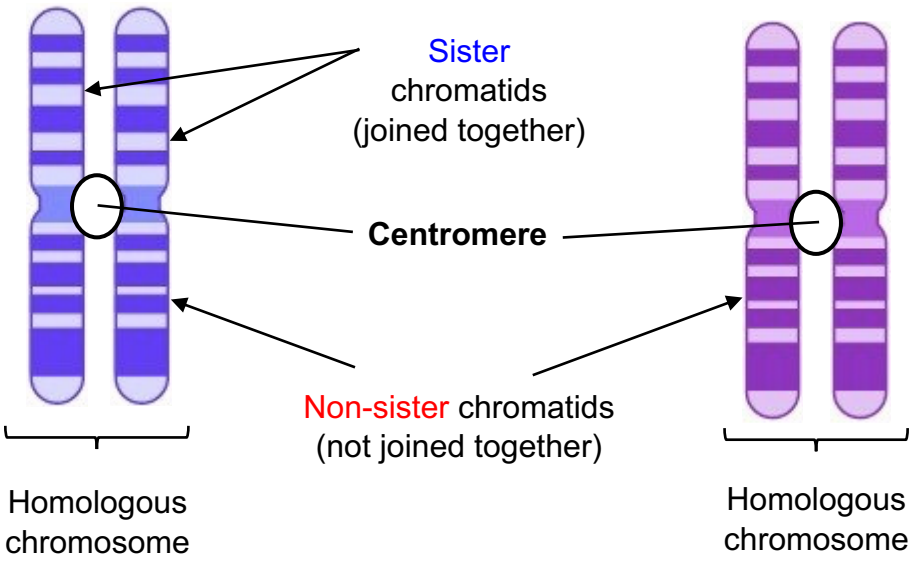
Why chromosomes look like an 'X'

Look at the **pair** of **homologous chromosomes** again:



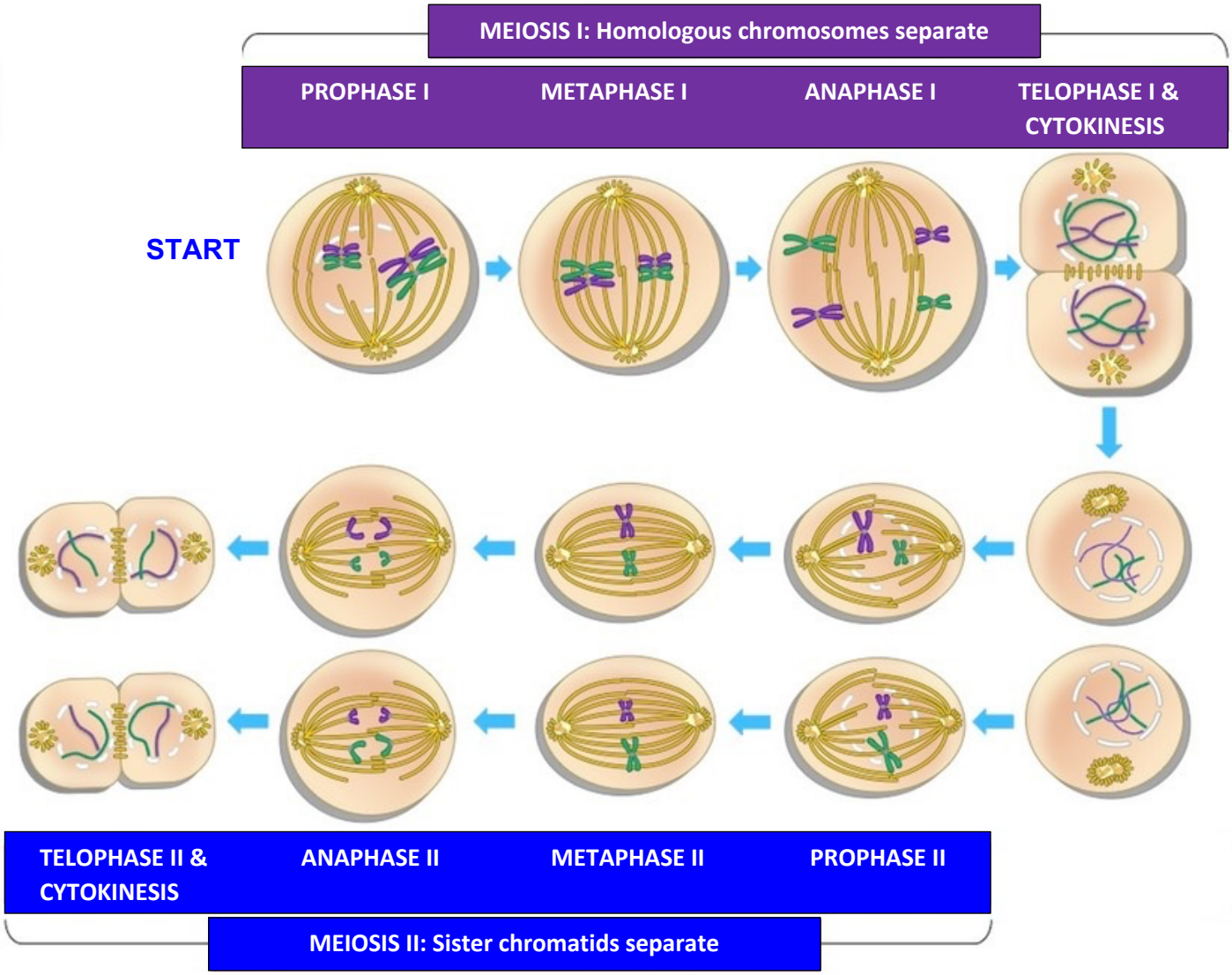
Homologous pair

- They look like this as they have **not been replicated** yet during **interphase**.
- **Interphase** happens **before cell division** (meiosis or mitosis)
- During **interphase**, a **copy** of each chromosome is **made** and it is **connected** to the **original chromosome** by a **centromere**, as shown below.



- Each homologous chromosome is made up of two sister chromatids (joined together).
- One sister chromatid is a copy of the original chromosome
- The sister chromatids are held together by a centromere
- It is these X-shaped chromosomes that undergo cell division (meiosis or mitosis).

C. THE PROCESS OF MEIOSIS



FIRST DIVISION	
• **Halves** the **number of chromosomes** • **Increases genetic variation** • **Separates homologous chromosomes**	
Prophase I	**Homologous chromosomes** pair up **Crossing over** happens where **chromatids break** and **recombine**
Metaphase I	**Homologous chromosomes** move to the **equator** of the cell
Anaphase I	**Homologous chromosomes separate** and **move** to **opposite poles**
Telophase I	**Homologous chromosomes** reach the **poles** and **unwind**
SECOND DIVISION	
• Produces **more cells** • **Similar** to **mitosis** • **Separates sister chromatids**	
Prophase II	**Chromosomes condense** and become **visible**
Metaphase II	**Chromosomes** move to the **equator** of the cell
Anaphase II	**Sister chromatids separate** and **move** to **opposite poles**
Telophase II	**Chromosomes** reach the **poles** and **unwind**

Contrast meiosis I and meiosis II

MEIOSIS I	MEIOSIS II
Homologous chromosomes pair up in **prophase**	**Homologous chromosomes do not pair up** in **prophase**
Crossing over occurs in **prophase**	**Crossing over does not occur** in **prophase**
Pairs of **homologous chromosomes move/line up** on **equator** in **metaphase**	**Single chromosomes move/line up** on **equator** in **metaphase**
Homologous chromosomes are **separated** in **anaphase**	**Sister chromatids** are **separated** in **anaphase**
Halves the **chromosome number**	Does **not half** the **chromosome number**
Produces **two** daughter cells	Produces **four** daughter cells
Increases genetic variation by **crossing over** and **random orientation of homologous chromosomes**	**Increases genetic variation** by **random assortment of chromatids** (into gametes)

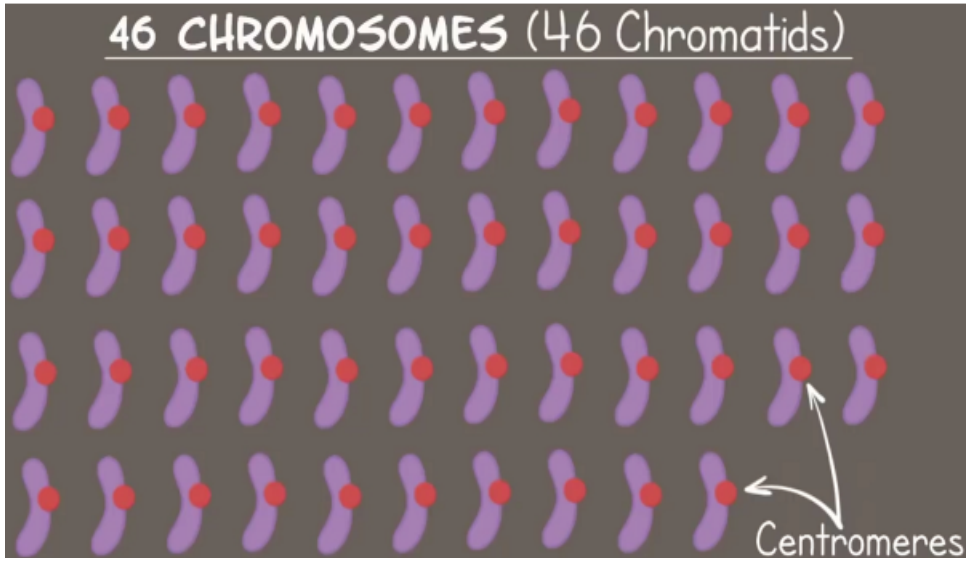
Comparing the number of cells, chromosomes and chromatids

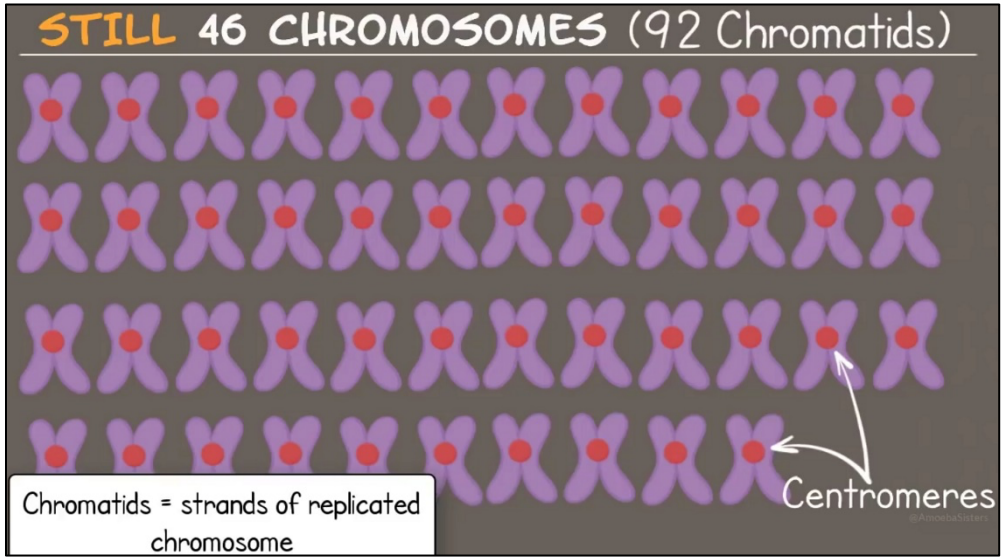
	Number of cells	**Number of chromosomes**	**Number of chromatids per chromosome**
Before meiosis starts	1	2n	2
At the **end** of the **first** division	2	n	2
At the **end** of the **second** division	4	n	1

C. NUMBER OF CHROMOSOMES AND CHROMATIDS IN DIFFERENT STAGES OF MEIOSIS

- By convention, we **count the number of centromeres** to give us the **number of chromosomes**.
- This confuses many students!

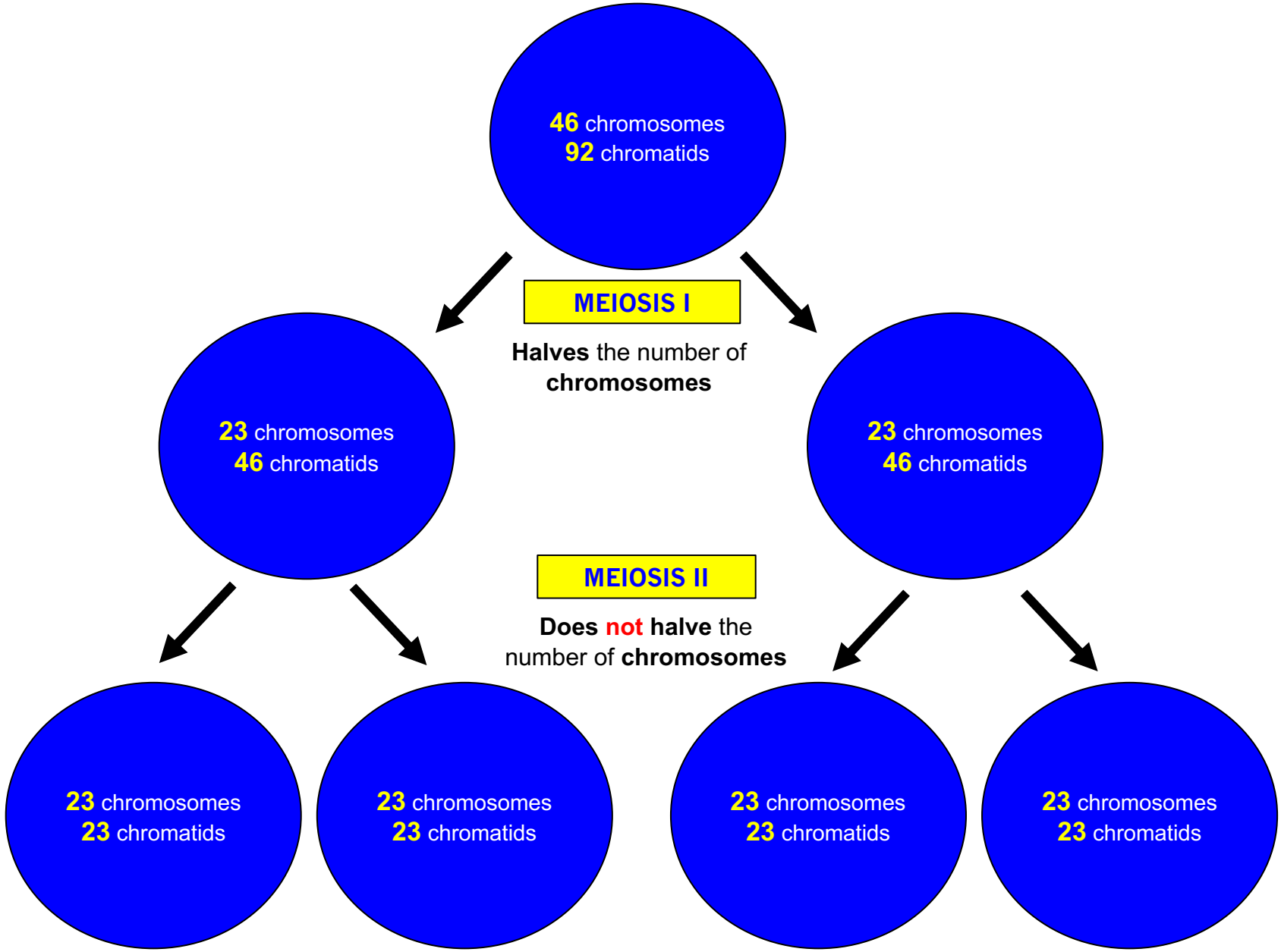
BEFORE DNA REPLICATION AND MEIOSIS	AFTER DNA REPLICATION AND AT THE START OF MEIOSIS





- Both diagrams show the **same number of chromosomes** but the one on the right has **double the number of chromatids**.
- We measure the **amount of DNA** in a cell by the **number of chromatids**.

IN HUMANS:


46 chromosomes
92 chromatids
MEIOSIS I
Halves the number of chromosomes
23 chromosomes
46 chromatids
23 chromosomes
46 chromatids
MEIOSIS II
Does not halve the number of chromosomes
23 chromosomes
23 chromatids
23 chromosomes
23 chromatids
23 chromosomes
23 chromatids
23 chromosomes
23 chromatids

Amended Exam Question

A **sex cell** from an organism contains **14 chromosomes**.

(a) Complete the table to show how many chromosomes or chromatids would have been present in **this cell** at different stages of meiosis.

Description	Number
Number of **chromosomes** at the **start of meiosis**	**28**
Number of **chromatids** at the **start of meiosis**	**56**
Number of **chromatids** in **metaphase I**	**56** (cell has not yet split)
Number of **chromatids** in **metaphase II**	**28** (not 14 until the cell splits)

(b) The amount of DNA in this **sex cell** is **x**.

What would be the amount of DNA present in this cell at the start of meiosis?

Explain your answer.

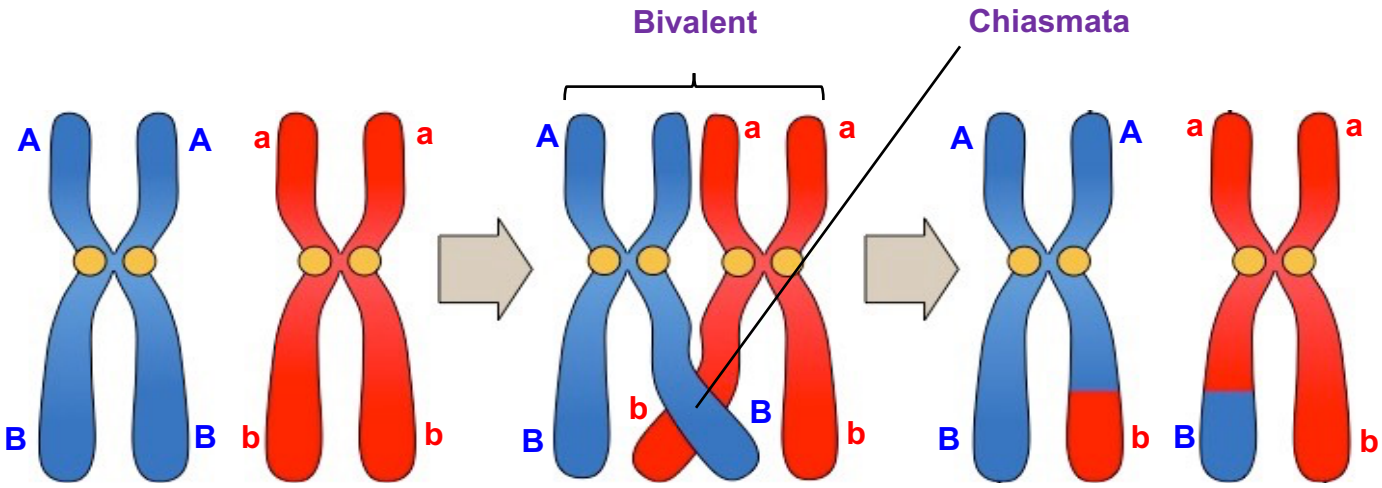
Amount of DNA (at start of meiosis) **= 4x (1);**

(As) there are 4x more chromatids (at the start) **(1);**

E. HOW MEIOSIS INCREASES GENETIC VARIATION

1. Crossing over of alleles in Prophase I

- Consider two genes, **A** and **B**, on a homologous chromosome.
- In **prophase I**, homologous chromosomes undergo a process called **synapsis**, whereby they **pair up** to form a **bivalent** (or **tetrad** = **four sister chromatids**).



Homologous chromosomes **pair up**

= **BIVALENT** forms

= **TETRAD** forms

Homologous chromosomes **held together** at points called **chiasmata**

Parts of **non-sister** chromatids are exchanged between them by **breaking** and **re-joining**

They **exchange alleles** between them

Produces **chromatids** with a **new combination** of **alleles**

Sister chromatids are no longer identical

A greater combination of **alleles** and **genetically different gametes** are now possible.

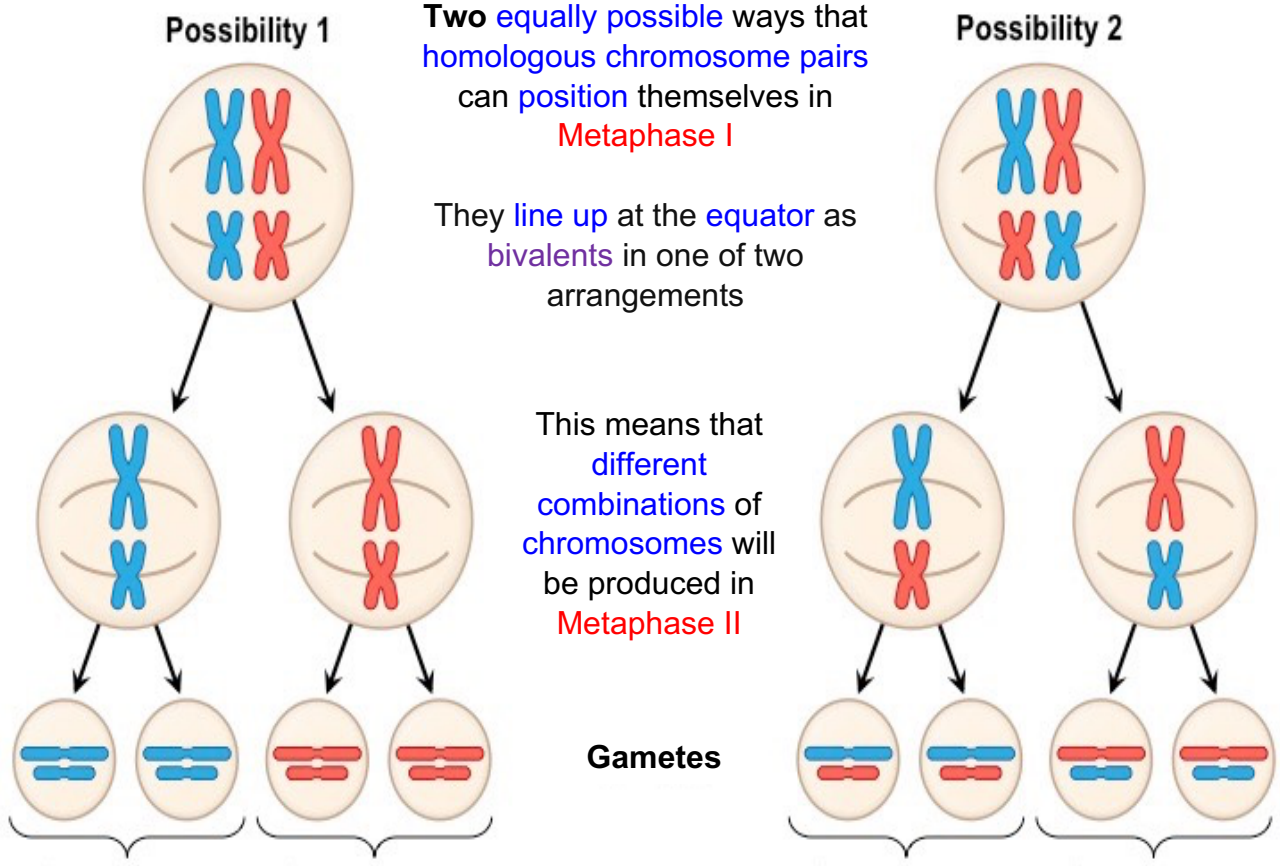
It is random where along the length of the chromosome crossing over occurs

Crossing over is also a rare event – it occurs at a low frequency

This further increases genetic variation

2. Random orientation of homologous chromosomes in Metaphase I

- This is also known as **independent assortment/segregation**.
- The **orientation** of **pairs** of **homologous chromosomes** in **metaphase I** is **random**.



This means that a greater combination of different alleles is possible in the gametes

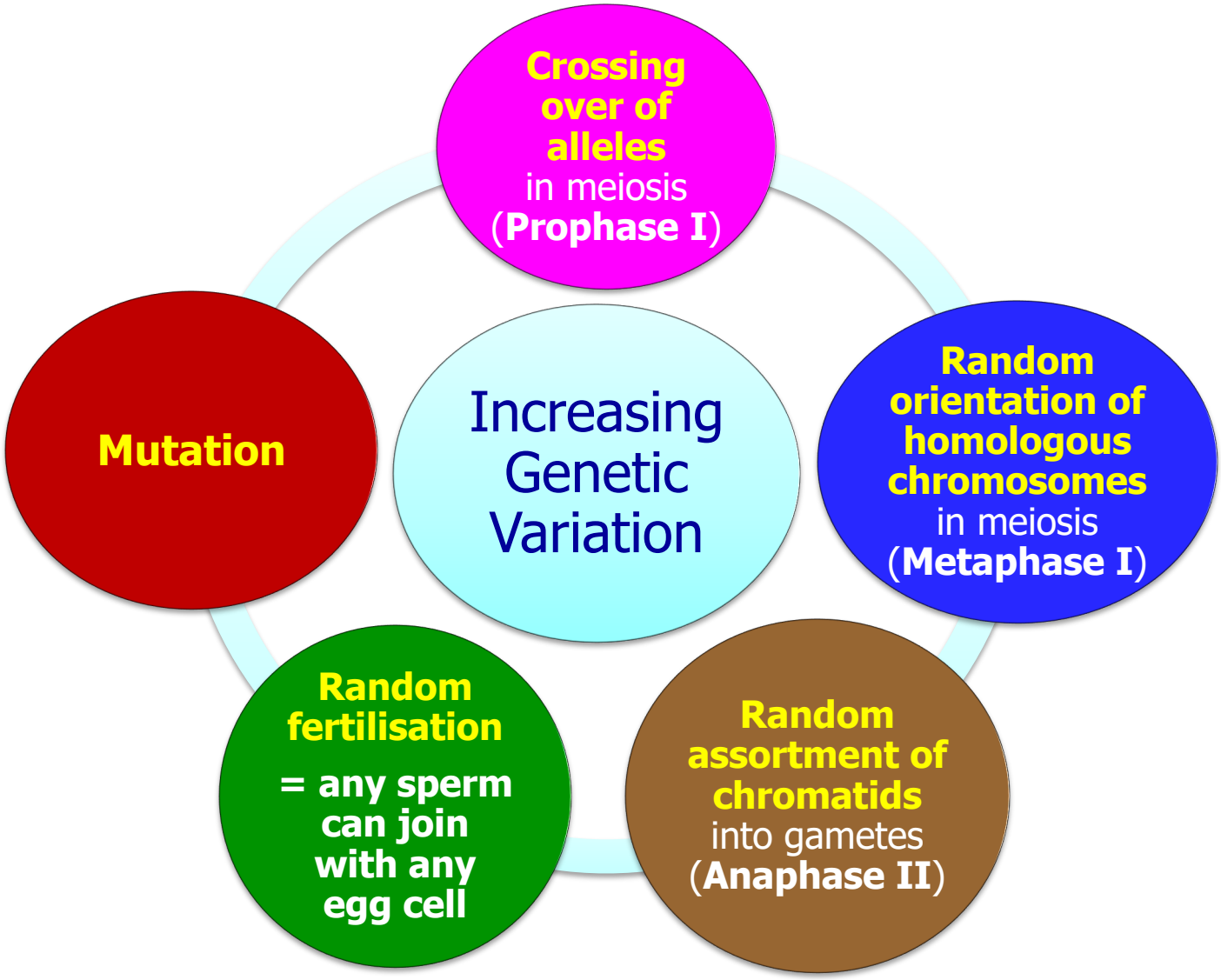
- Different gametes have different combinations of maternal and paternal chromosomes.

In humans, the number of different combinations of chromosomes possible in gametes is:

2^{23} = over **8 million**

F. INCREASING GENETIC VARIATION

- **Three** of these ways involve **meiosis**

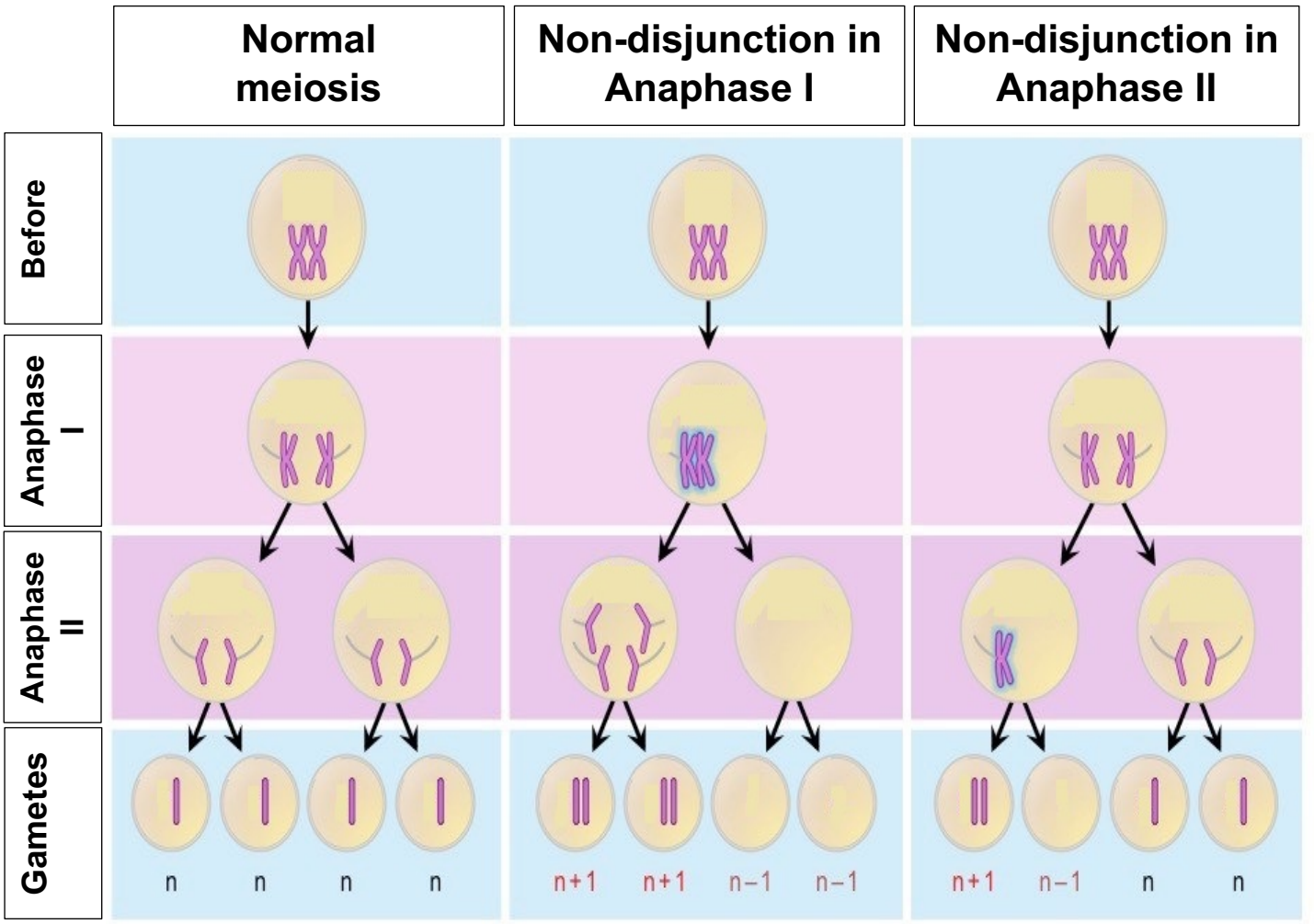


Natural selection DECREASES genetic variation

G. DOWN SYNDROME

How it occurs

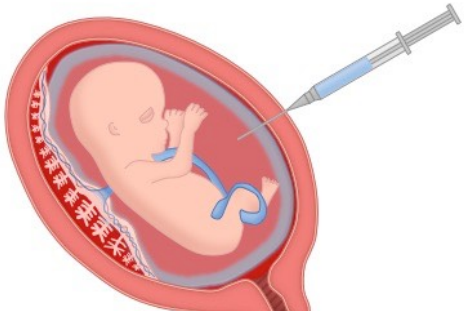
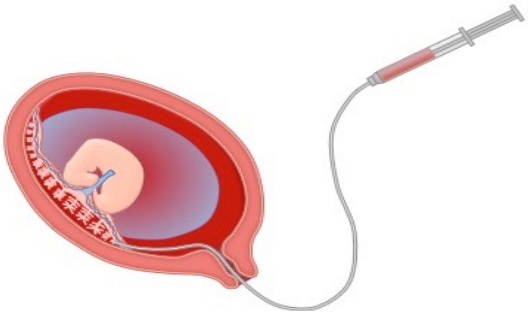
- Individuals with Down syndrome have three copies of chromosome 21 (= 'trisomy 21').
- It is caused by non-disjunction.
- This is where chromosomes do not separate in Anaphase I or II of meiosis, so they move to the same pole of the cell.
- This causes the gametes to have either one extra chromosome or one chromosome less.



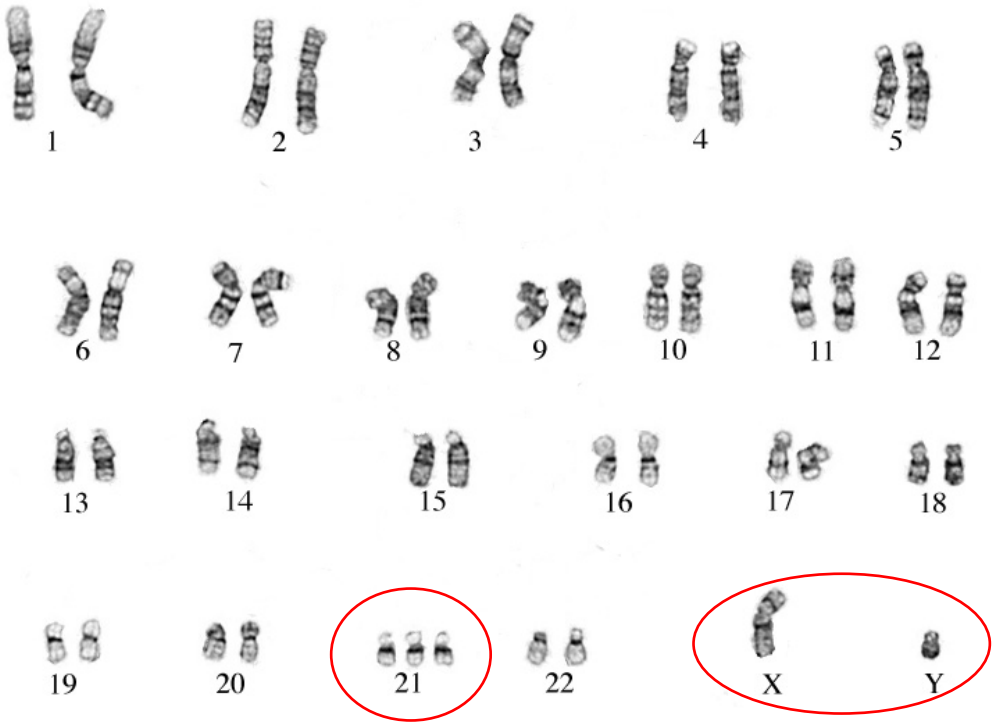
- Non-disjunction of chromosome 21
- Homologous chromosomes do not separate in Anaphase I
- Due to incorrect attachment to the spindle

  OR
- Sister chromatids do not separate in Anaphase II
- Due to centromeres not dividing/splitting
- (So) they move to the same pole
- Gametes can have one extra chromosome or one less chromosome
- Gamete with 2 copies of chromosome 21 fertilises a normal gamete
- Zygote produced has 3 copies of chromosome 21
- Risk of Down syndrome increases as the mother's age increases

Two methods used to obtain cells from an unborn child for chromosome testing

Amniocentesis	Chorionic villus sampling (CVS)
	
Needle used to withdraw foetal cells from the **amniotic fluid**	**Suction tube** used to withdraw foetal cells from the **chorion** (where the placenta will develop from)
Inserted through the **abdominal wall** and **uterus wall**	Inserted through the **cervix** (neck of the uterus)
Usually done **later** in pregnancy (16 weeks)	Can be done **earlier** in pregnancy (11 weeks)
Slight risk of inducing **miscarriage** (~1%)	**Slightly lower risk** of **miscarriage** (~0.5%)

- The chromosomes can then be arranged in **homologous pairs** to produce a **karyogram**.
- Doctors can then check the baby's **sex** and look for any **chromosome abnormalities**.



This is a **male** with **Down syndrome**