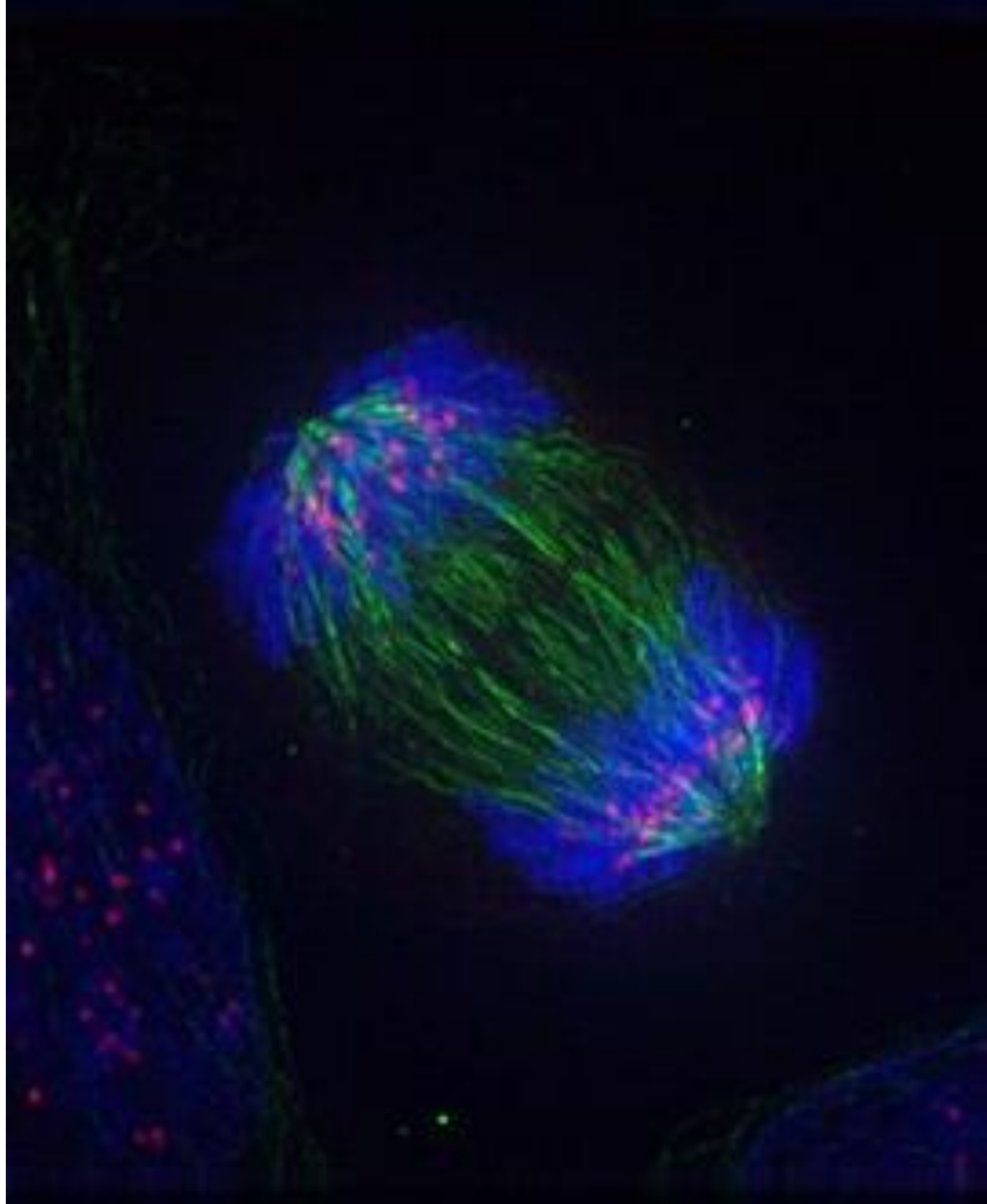
DP Biology – D2.1

Cell and nuclear division

- How are large numbers of cells with identical genes produced?
- How do eukaryotes make genetically varied cells that can become gametes?

SL statements D2.1.1–11. Textbook pp. 648–661.
Image: a cell in anaphase, stained. Roy van Heesbeen, public domain.



Objectives for each class

Class	Statements	By the end of the class, you can…
1	D2.1.1, 4, 5	Explain why cells divide, the roles of mitosis and meiosis, and why DNA is replicated first
2	D2.1.6–7	Describe condensation and movement of chromosomes, and the phases of mitosis
3	D2.1.8, 2, 3	Identify phases in a micrograph, and compare forms of cytokinesis
4	D2.1.9–11	Explain how meiosis gives four haploid nuclei, how non-disjunction happens, and how meiosis generates variation

Overview of this chapter

Part	Statements	What it covers
Why cells divide	D2.1.1, 4, 5	New cells, mitosis, meiosis and replication
Moving chromosomes	D2.1.6	Histones and microtubules
Mitosis	D2.1.7–8	Phases and how to identify them
Splitting the cell	D2.1.2–3	Cytokinesis, equal and unequal
Meiosis	D2.1.9–11	Reduction, errors and variation

New cells come from cell division

D2.1.1

- A **parent cell**, often called a mother cell, divides to form two **daughter cells**
- New cells are made only by division of existing cells

Need	What division provides
Growth	More cells in a multicellular organism
Repair	New cells to close a wound
Maintenance	Replacement of worn out cells, such as skin cells
Reproduction	Gametes in sexual reproduction; new individuals in asexual reproduction

Key idea

Division happens in all living organisms. In eukaryotes the nucleus divides first, and then the cytoplasm.

What mitosis and meiosis each do

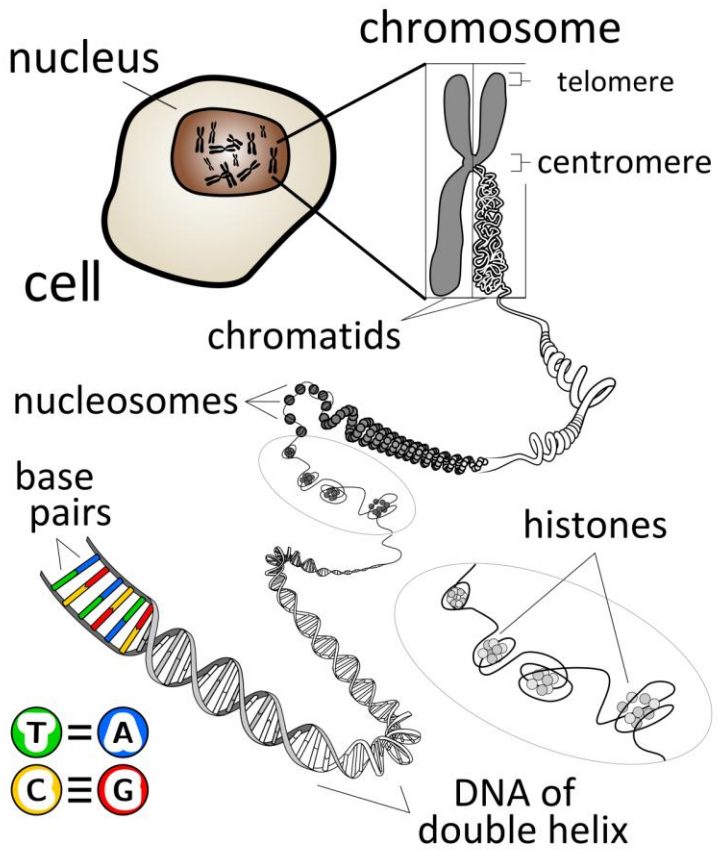
D2.1.4

	Mitosis	Meiosis
Chromosome number	Maintained	Halved
Genome	Maintained, so the nuclei are identical	Changed, which generates diversity
Number of divisions	One	Two
Used for	Growth, repair, asexual reproduction	Making gametes in sexual life cycles

Why divide the nucleus first?

A cell with no nucleus is anucleate. Nuclear division comes before cell division, so that each daughter cell receives a nucleus. Without a nucleus, a cell cannot make most of its proteins for long.

DNA is replicated before division



Structure of a chromosome. KES47, CC BY 3.0.

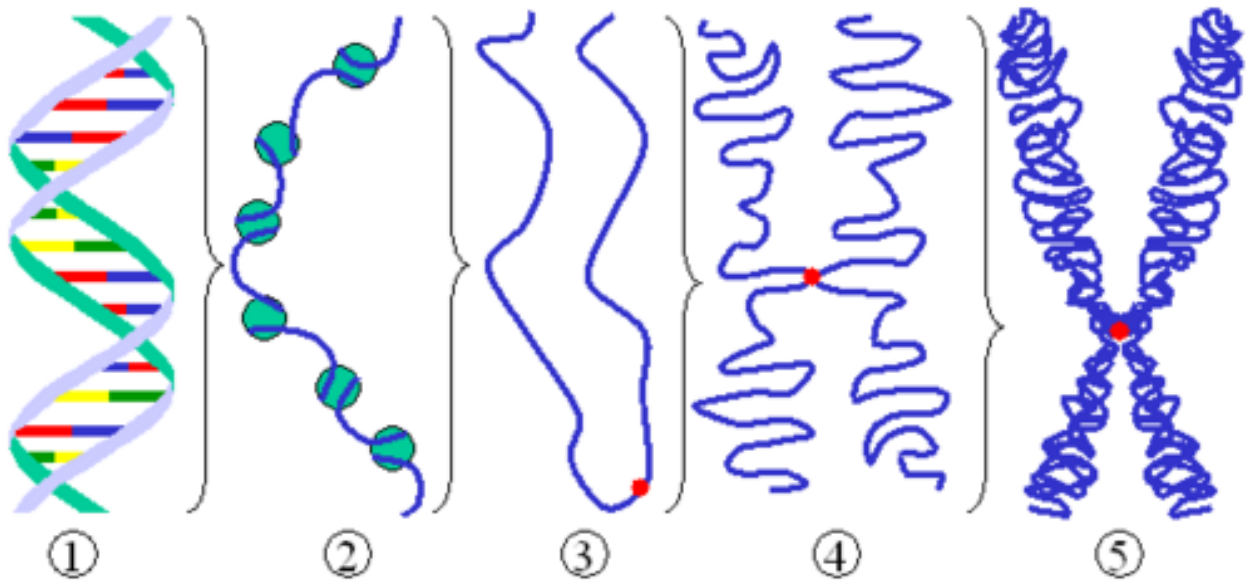
- Replication happens in **interphase**, before mitosis or meiosis begins
- Each chromosome then has two DNA molecules, called **chromatids**
- Chromatids are held together at a **centromere**
- Each new nucleus can then receive a full set of genes

Common mistake

After replication a cell still has the same number of chromosomes. Each one has two chromatids. Separated chromatids are then counted as separate chromosomes.

Condensation by supercoiling

D2.1.6



From a double helix to a chromosome. Magnus Manske, CC BY-SA 3.0.

- In interphase DNA is long and thin: **chromatin**
- DNA wraps around proteins called **histones**
- Further coiling produces short, compact chromosomes
- This is called **supercoiling**

Key idea

A human nucleus holds about 2 metres of DNA. Condensation allows chromosomes to be moved without knots or breaks. This shared feature of mitosis and meiosis is what makes them visible with a light microscope.

Moving chromosomes with microtubules

D2.1.6

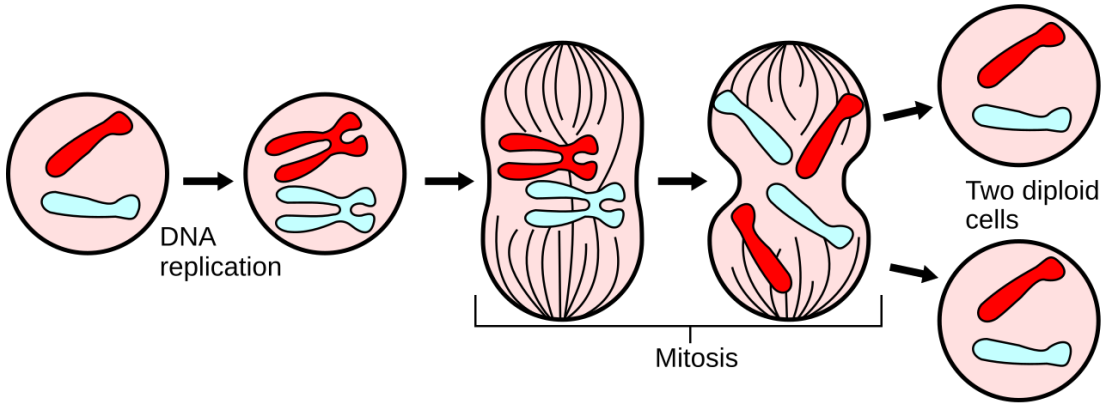
Term	What it is
Microtubules	Hollow protein cylinders that form the spindle
Spindle	Microtubules stretching across the cell between its two poles
Centromere	The point where the two chromatids are held together
Centrosome	Region near the nucleus in animal cells, which organises microtubules
Microtubule motors	Proteins, at the centromere and elsewhere, that use ATP to move chromosomes

Common mistake

Centromere, centrosome and centriole sound alike, but they are different structures. Chromatid and chromosome are also commonly confused.

The phases of mitosis

D2.1.7



Major events in mitosis. Mysid, public domain.

Phase	What happens
Prophase	Chromosomes condense; the nuclear membrane breaks down; a spindle forms
Metaphase	Chromosomes line up at the equator; microtubules attach to each centromere
Anaphase	Chromatids separate; they are pulled to opposite poles
Telophase	Nuclear membranes reform; chromosomes uncoil; cytokinesis usually follows

Why the daughter cells are identical

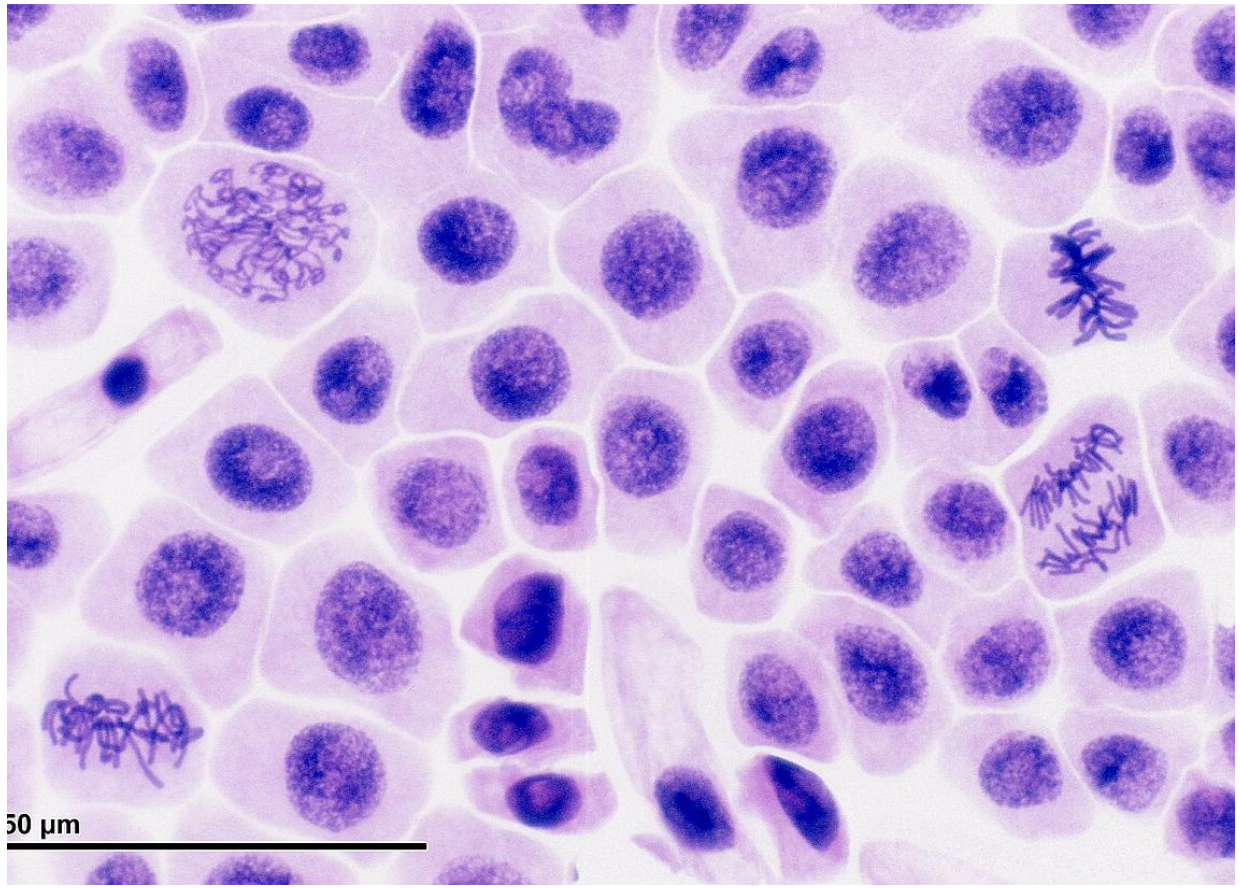
D2.1.7

Stage	What makes it exact
Interphase	DNA is copied, with identical base sequences
Metaphase	Chromosomes line up with one chromatid facing each pole
Anaphase	One chromatid of each chromosome moves to each pole
Telophase	Each new nucleus has one complete set of chromosomes

Activity

Start with a cell that has 2n = 4 chromosomes. Draw it at each phase. Count the chromosomes and the DNA molecules at each stage.

Identifying the phases of mitosis



Onion root tip cells in mitosis. Josef Reischig, CC BY-SA 3.0.

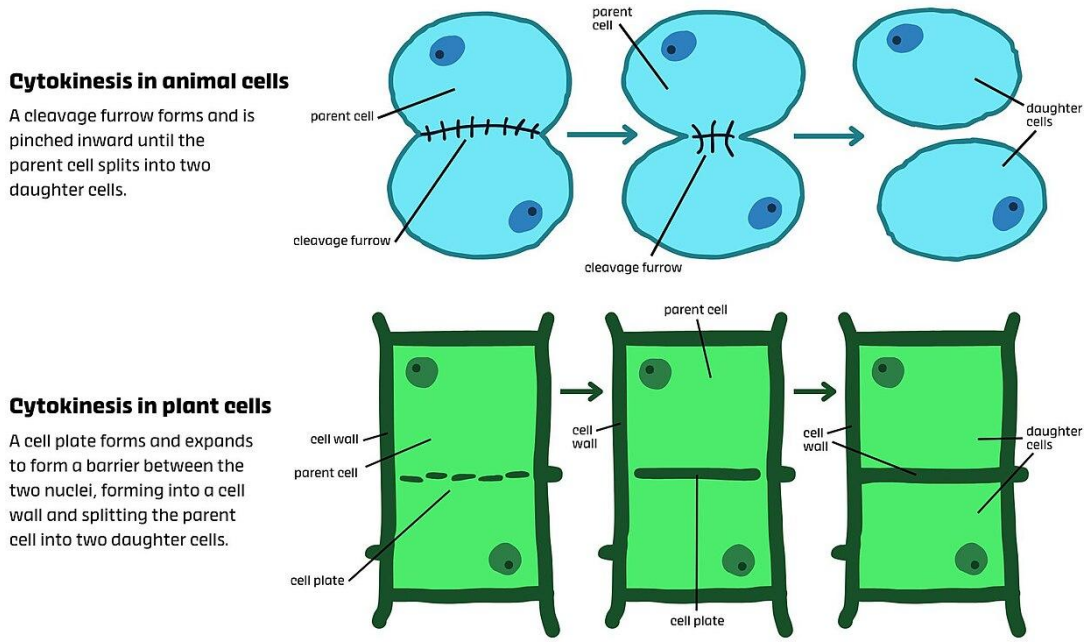
- **Prophase:** threads visible, no clear line
- **Metaphase:** a line at the centre
- **Anaphase:** two groups moving apart, V shapes
- **Telophase:** two groups at the poles, and a new wall

Activity

Find one cell for each phase. Then use **mitotic index** = cells in mitosis / total cells. If 18 of 150 cells are dividing, the index is 18 / 150 = 0.12.

Cytokinesis: splitting the cytoplasm

D2.1.2



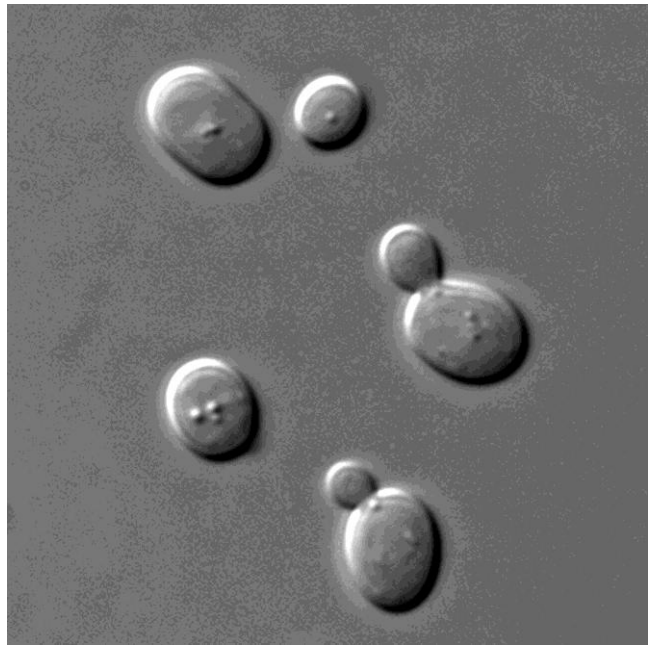
Cytokinesis in animal and plant cells. John Brian Eatmon, CC BY 4.0.

Cell	How it splits
Animal	A ring of **actin and myosin** contracts, pinching the membrane together at the equator
Plant	**Vesicles** gather at the equator, and they assemble sections of membrane and cell wall

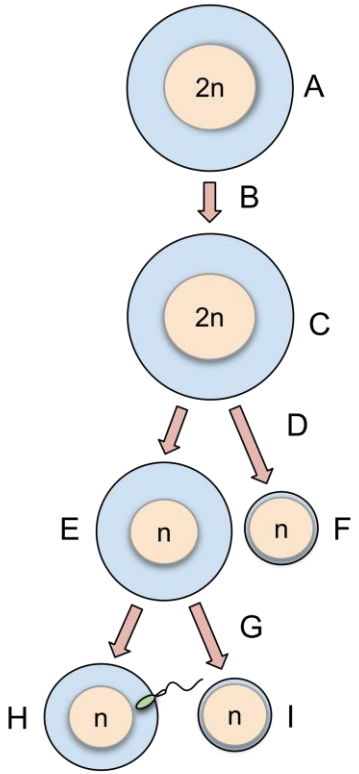
Key idea

Plant cells cannot pinch in, because their cell walls are rigid. They build a new wall from the centre outwards. In both cases, cytokinesis follows division of the nucleus.

Equal and unequal cytokinesis



Budding yeast. Masur, public domain.



Oogenesis. Leiladavids, CC BY-SA 4.0.

- Cytoplasm is usually shared **equally**
- In **oogenesis**, the egg keeps most cytoplasm, and polar bodies are small
- In **yeast budding**, a small bud forms on the parent cell
- Every daughter cell needs at least one **mitochondrion**, and any other organelle made only by dividing an existing one

Question

Why is it useful for an egg to keep most of the cytoplasm, when meiosis produces four nuclei?

Meiosis is a reduction division

D2.1.9

Term	Meaning
Diploid (2n)	Two sets of chromosomes, in homologous pairs. Human body cells: 46
Haploid (n)	One set of chromosomes. Human gametes: 23
Homologous	Same genes in the same order, but the alleles may differ

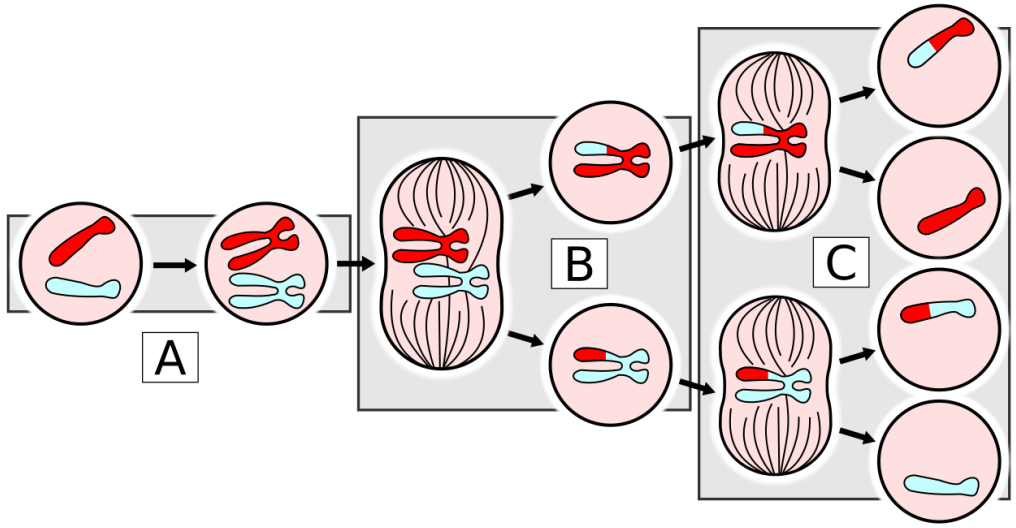
- One diploid nucleus gives **four haploid nuclei**
- Sexual life cycles need this: fertilization doubles the number, and meiosis halves it again

Common mistake

Haploid is not simply half the DNA at random. Each nucleus receives one chromosome of every homologous pair.

Two rounds of segregation

D2.1.9



Major events in meiosis. PatriciaR, public domain.

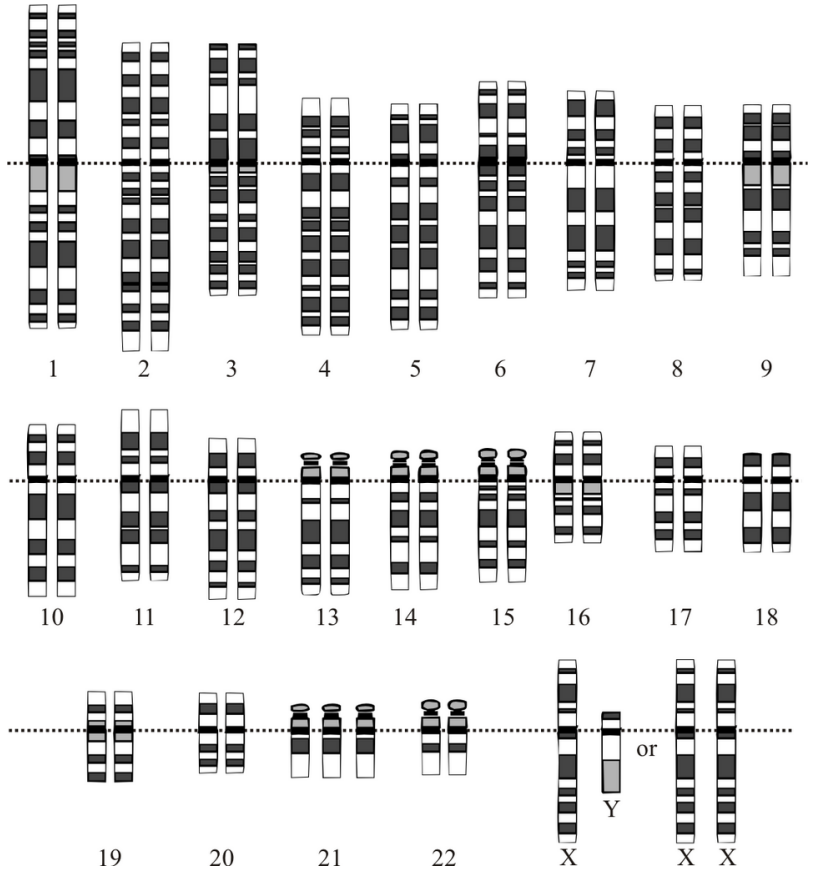
	Meiosis I	Meiosis II
Separates	**Homologous chromosomes**	**Sister chromatids**
Result	Two haploid nuclei, chromosomes still have two chromatids	Four haploid nuclei, chromosomes have one chromatid

Comparing mitosis and meiosis

D2.1.9

	Mitosis	Meiosis
DNA replicated first?	Yes	Yes, once only
Homologous pairs form?	No	Yes, in prophase I
Nuclei produced	Two	Four
Chromosome number	Stays the same	Halved
Daughter nuclei	Identical	Genetically different
Shared features	Condensation, microtubules, spindle	Condensation, microtubules, spindle

Non-disjunction and Down syndrome



Karyotype showing three copies of chromosome 21. National Human Genome Research Institute, public domain.

- **Non-disjunction**: chromosomes fail to separate in meiosis
- One gamete has an extra chromosome, and another has one fewer
- If a gamete with two copies of chromosome 21 is fertilized, the zygote has three
- This is **trisomy 21**, called **Down syndrome**, with 47 chromosomes in total

Data

Risk rises steeply with the age of the mother, from about 1 in 1000 live births at age 30 to about 1 in 100 at age 40. Weigh up what this does and does not tell parents.

Variation: random orientation

D2.1.11

- In metaphase I, each pair of homologous chromosomes, called a **bivalent**, lines up at random
- The orientation of one pair has no effect on any other
- So many combinations of maternal and paternal chromosomes can result

Haploid number (n)	Calculation	Possible combinations
2	2 × 2	4
3	2 × 2 × 2	8
23, in humans	2 to the power 23	Over 8 million

Key idea

And this is before fertilization, in which any one of these eggs can fuse with any one of these sperm.

Variation: crossing over

D2.1.11

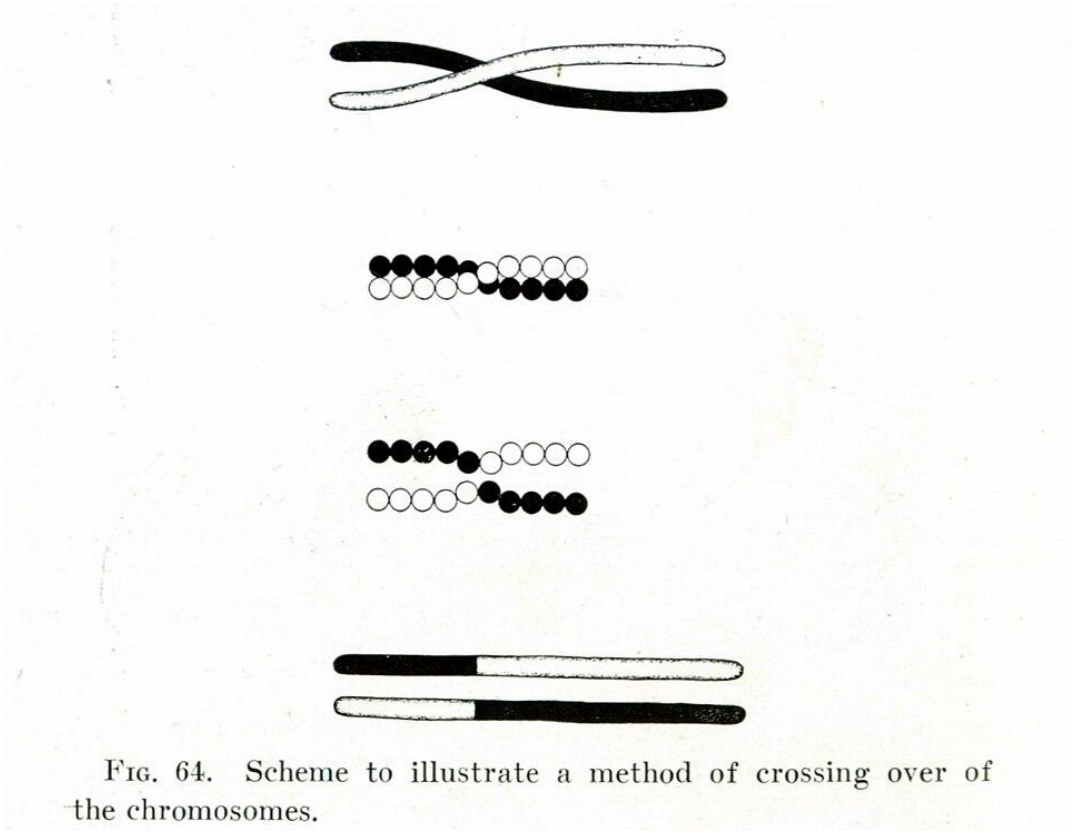


Fig. 64. Scheme to illustrate a method of crossing over of the chromosomes.

A historical drawing of crossing over, Morgan, public domain.

- Homologous chromosomes pair up in prophase I
- **Non-sister chromatids** break and swap sections
- Each chromosome now carries a new combination of alleles
- So this is a further source of variation, on top of random orientation

Common mistake

Crossing over does not create new alleles, and it involves non-sister chromatids. Swapping between identical sister chromatids would change nothing.

Check that you can explain

1. Why nuclear division comes first
2. Why DNA is replicated beforehand
3. Histones and microtubules
4. The phases of mitosis, and how to identify them
5. Cytokinesis in plants and animals
6. Equal and unequal cytokinesis
7. Diploid, haploid and homologous
8. The two rounds of segregation in meiosis
9. Non-disjunction and Down syndrome
10. Random orientation and crossing over

Exit activity: 5 minutes

On your own and without notes. Hand this in as you leave.

1. A cell has 2n = 8. State how many chromosomes each daughter nucleus has after mitosis, and after meiosis.

2. In which phase of mitosis do chromatids separate?

3. Give two ways in which meiosis generates genetic variation.

Image credits

Anaphase IF.jpg – Roy van Heesbeen – Public domain

Chromosome en.svg – File:Chromosome-es.svg: KES47 / derivative work: KES47 – CC BY 3.0

Chromatin chromosome.png – Magnus Manske – CC BY-SA 3.0

Major events in mitosis.svg – Mysid – Public domain

Mitosis (261 13) Pressed; root meristem of onion (cells in prophase, metaphase, anaphase, telophase).jpg – Doc. RNDr. Josef Reischig, CSc. – CC BY-SA 3.0

Cytokinesis in animal cells and plant cells.jpg – John Brian Eatmon – CC BY 4.0

S cerevisiae under DIC microscopy.jpg – Masur – Public domain

Oogenesis.svg – Leiladavids – CC BY-SA 4.0

MajorEventsInMeiosis variant int.svg – internationalization: PatríciaR. Original image from NCBI; o – Public domain

Down Syndrome Karyotype.png – Courtesy: National Human Genome Research Institute – Public domain

Morgan crossover 1.jpg – Author not stated – Public domain

All from Wikimedia Commons (commons.wikimedia.org, search the file name). Some images are cropped. CC licences: creativecommons.org/licenses