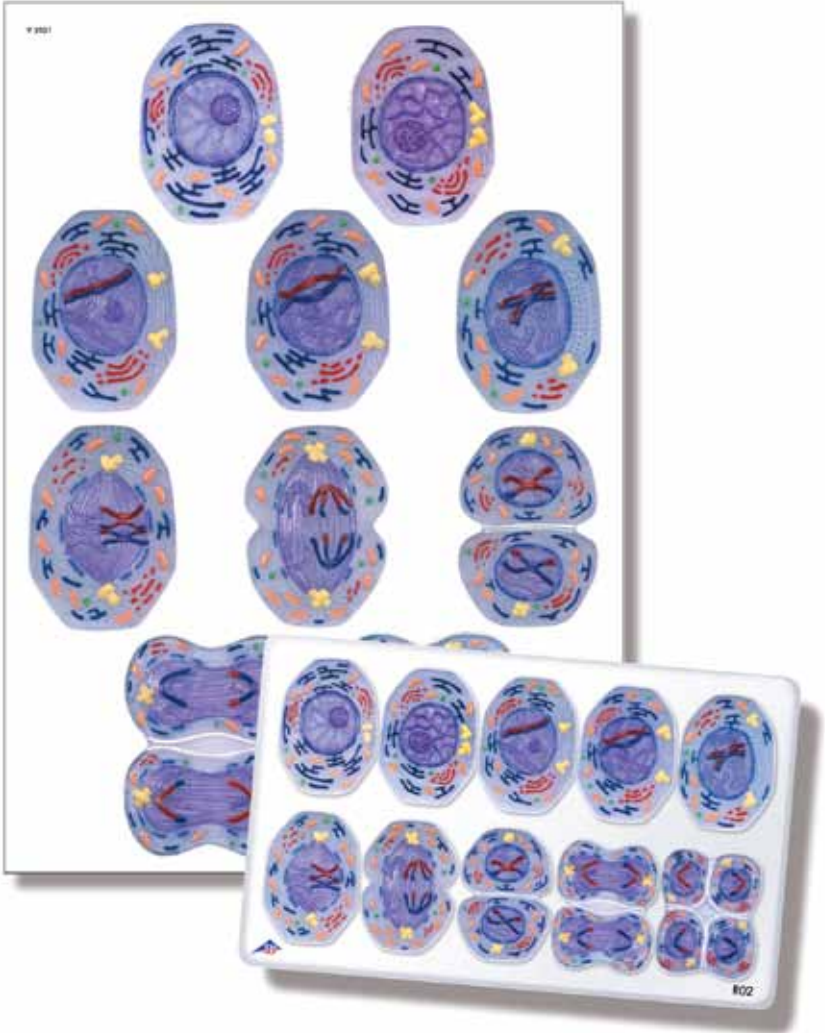




...going one step further



R02/1
V2051

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Meiosis, or reduction division, is a special type of cell division. Depending on the organism and cell type, it can take anything from several days to years, resulting in the production of sex cells (gametes). Each gamete precursor cell produces four gametes through reduction division. In general, there are two types of gametes. Large, immobile cells are referred to as egg cells or oocytes, and small, mobile gametes as sperm cells or spermatocytes.

Egg cells are formed by meiotic division from precursor cells in the ovaries. Human egg cells already begin to mature in the embryo (3rd to 8th month of pregnancy), however, the cells remain in a meiotic intermediate phase until sexual maturity is reached. From then on, some of the immature egg cells complete the meiotic division at regular intervals under the control of hormones. The maturation of human sperm cells occurs regularly in the testes when sexual maturity has been reached. In this case, a complete meiotic division takes 20-24 days.

Usually, body cells (e.g. precursor cells of the gametes) contain a double (diploid) chromosome complement, with one half of the chromosomes originating from the mother and the other half from the father. Therefore, a twin copy exists of each chromosome, i.e. as a matching (homologous) pair of chromosomes. By contrast, the gametes contain only a single (haploid) chromosome complement. In other words, egg or sperm cells only contain half of the mother's or father's genetic information, so that when both cells join, a new cell (zygote) with a complete diploid chromosome complement can originate.

The purpose of meiosis is therefore to reduce the normally diploid chromosome complement of a gamete precursor cell to the haploid complement to establish the basis of any sexual reproduction. A further important function of meiosis is to mix the genetic information. This is achieved by two mechanisms:

1. a random distribution of the maternal and paternal chromosomes to the sex cells being produced
2. the exchange of genes between the homologous chromosomes (genetic recombination)

(The underlying procedures of both mechanisms are explained below in the description of the individual phases).

In humans, who have 23 chromosomes in the haploid complement, the random distribution of the chromosomes alone allows for 2^{23} , i.e. 8.4×10^6 different genetic possibilities of variation. The number of variations is furthermore increased by the exchange of genes between the chromosomes.

Prior to the meiotic division, the gamete precursor cells are in the interphase, which refers to the period between two (mitotic or meiotic) cell divisions. The interphase comprises three stages:

- **G₁ phase (presynthesis)** The stage where the cell grows.
- **S phase (synthesis)** In this phase, the centrioles and the DNA (deoxyribonucleic acid) begin to duplicate.
- **G₂ phase (postsynthesis)** This phase separates the end of the DNA synthesis from the phase of division. Furthermore, the duplication of the centrioles is completed.

Meiosis, the phase following the interphase, comprises two successive maturation (meiotic) divisions, which are separated by a short, specific interphase (interkinesis). As in mitosis, several stages of division are differentiated in each meiotic division:

First meiotic division:

- Prophase I (four subsections: leptotene, zygotene, pachytene and diplotene with diakinesis)
- Metaphase I
- Anaphase I
- Telophase I
- Cytokinesis I

Interkinesis

Second meiotic division:

- Prophase II
- Metaphase II
- Anaphase II
- Telophase II
- Cytokinesis II

The 3B Scientific® model series on meiosis (product no. R02) and the wall chart on meiosis (V2051M, V2051U) show a typical mammal cell at an enlargement of approx. 10,000 times. In the lower third of the models/illustrations the cell organelles are portrayed open.

The 3B Scientific® model series on meiosis is supplied in a storage system, which is equipped with a hanging device. The model series can thus be simply hung on a wall in order to save space. The models also have magnets at the rear so that they can be arranged on magnetic boards in the classroom for teaching purposes.

At the end of this description you will find illustrations of the 10 phases included. You can use these to make photocopies for your lessons. By colouring, labelling and correctly arranging the individual phases your students can easily review and memorize what they have learned.

Free colour illustrations of the individual stages are also available on the Internet at www.3bscientific.com.

1. Interphase, stage of the G₁ phase

Inside the cell the nucleus with the nucleolus (1) and its nuclear membrane (2) can be seen. The nucleus also contains the not yet helical DNA (3) with the genetic information.

The cell itself receives its stability and shape from very fine tubes, the so-called microtubules (4) extending through the cytoplasm. The microtubules control, among other things, the cell movements and the intracellular transport processes.

In the cytoplasm, the endoplasmic reticulum (5) can be seen. This is an intertwined tube system mainly in charge of lipid synthesis, ion storage and redesigning and transporting certain proteins. The membrane of the rough endoplasmic reticulum has ribosomes attached to it, which synthesize the proteins passing through the endoplasmic reticulum.

The Golgi complex (or apparatus) (6) can also be referred to as “cell gland”. It is made up of stacks of layered hollow sacs (Golgi cisternae), which swell up as the vesicles become too small and “pinch off” (Golgi vesicles) (7). The Golgi complex receives membrane components and enzymes from the endoplasmic reticulum. Its main function is collecting, packing and transporting secretions and producing lysosomes (digestion vesicles) (8).

The main job of the lysosomes is breaking down cell components (= intracellular digestion).

The mitochondria (9) are in charge of producing energy for the cell.

The job of the centrioles (10) is to build up the cleavage spindle. They are hollow cylinders made up of longitudinally arranged tubes (microtubules).

2. Prophase I

The prophase of the first meiotic division is the part of meiosis that takes longest. In the course of this phase, chromosomes and chromatin change their structure and arrangement within the nucleus in a

specific order. Therefore, prophase I is split up into four subsections (leptotene, zygotene, pachytene and diplotene with diakinesis). In contrast to the mitotic prophase, which lasts several hours, meiotic prophase I can take days, weeks, months or years.

Leptotene

At the beginning of prophase I (leptotene), the nucleolus (1) and the nuclear membrane (2) can be seen. The chromosomes (3) are now visible as individual, long, thin threads. Its ends are attached within the nuclear membrane. Each chromosome has already been replicated (duplicated) during the interphase and is made up of two sister chromatids, which however are so close to each other that they cannot be differentiated. The centrioles were also duplicated in the interphase. Both pairs (4) begin to move in opposite directions towards the two cell poles. Between them the so-called central spindle (5) begins to build up, which consists of many microtubules.

3. Zygotene and Pachytene

One maternal (1) and one paternal homologue (2) (consisting of two sister chromatids) of one chromosome pair are shown in different colours to represent the other chromosomes (2 x 23 in total).

Zygotene

The zygotene phase is initiated as soon as the homologous chromosomes begin to line up side by side to form the synaptonemal complex (3) (parallel arrangement of the homologous partners). This process usually begins at the ends of the chromosomes and continues down to the other end, similar to a zipper. The chromosome pairing (synapsis) occurs with high precision, so that the matching genes of the homologous chromosomes face each other directly. This is an important requirement for the recombinant exchange of gene sections (crossing over). The homologous chromosome pairs in meiotic prophase I are usually referred to as bivalent, but since each homologous chromosome consists of the closely arranged sister chromatids, they can also be referred to as tetrads.

Pachytene

As soon as all synaptonemal complexes are fully developed, i.e. the homologous chromosomes have all lined up, the pachytene phase begins. From now on, recombination nodes (4) become visible at intervals on the synaptonemal complexes, where the exchange of gene sections occurs.

4. Diplotene

After some gene sections have been exchanged, the homologous chromosomes (1) disjoin more and more, remaining connected at one or more points of crossing over (chiasma bridges or chiasmata) (2). The chiasma bridges are the places where the genetic recombination (exchange of maternal and paternal genetic information) occurred earlier. Egg cells can persist in the diplotene phase for months or even years.

5. Diakinesis

The end of meiotic prophase I begins when the chromosomes detach from the nuclear membrane (1). The chromosomes are condensed and the sister chromatids, joined by centromeres (short DNA sequences with a high AT level) (2), become visible. The non-sister-chromatids in which an exchange of gene sections occurred remain connected via chiasma bridges (3).

The phase following prophase I is metaphase I. The meiotic phases remaining at this point take up less than 10% of the total time required for a complete meiosis.

6. Metaphase I

During the transition from prophase I into metaphase I, the centriole pairs (1) have reached the two oppo-

Meiosis

English

site cell poles. A spindle apparatus has developed and the nuclear membrane (2) dissolves. The chromosomes align at the equator level, forming the so-called metaphase plate. Viewed from the top, the chromosomes have a star-like shape (monaster or "mother" star). The kinetochores (3) are protein complexes which already have developed at the centromeres. A particularity of meiotic metaphase I is that the kinetochores of each sister chromatid pair seem to have merged. The microtubules (4) of the central spindle, which now have attached themselves precisely to the kinetochores of each sister chromatid pair (5), therefore all point in the same direction. The chiasma bridges (6) are still intact. They play an important part in the correct line-up of the homologous chromosomes at the equator level.

The endoplasmic reticulum (7) and the Golgi complex (8) have now been almost completely dissolved.

7. Anaphase I

In anaphase I of meiosis, the homologous chromosomes (1) disjoin and not, as in mitosis, the sister chromatids. In this process the chiasma bridges are dissolved, which so far held together the maternal and paternal chromosomes.

Some mutant organisms, where meiotic crossing over occurs only on a limited level, have chromosome pairs without chiasma bridges. These pairs are usually not fully disjoined (nondisjunction) and the resulting daughter cells have one chromosome too few or too many. Such malformations are referred to as numerical chromosome aberrations, which cause deformities.

Disjunction begins at the kinetochores (2), the place where the traction fibres of the central spindle are attached. From here, the chromosomes are pulled slowly towards the centrioles (4) located at the cell poles, moving along the microtubules (3) which create a traction effect as they become shorter. The microtubules (5) that are not connected to chromosomes now become longer, thus increasing the distance between the centrioles and elongating the cell. At the equator level, the beginning stage of a cleavage furrow (6) becomes visible.

The process of crossing over during the prophase and the random distribution of the maternal and paternal chromosomes to the cell poles result in a variation of the genetic information (ref. to introduction)

8. Telophase I, Cytokinesis I, Interkinesis, Prophase II and Metaphase II

Telophase I and Cytokinesis

In telophase I, the spindle disintegrates and a ring constriction (1) develops at the equator level. In addition, a thin nuclear membrane develops (2). During the following phase of cytokinesis, the cell body is divided exactly at the middle, at the ring constriction between the two new daughter nuclei (3). The daughter nuclei each contain the maternal or paternal chromosome complement slightly varied through the process of crossing over, with the DNA already present in duplicate, i.e. one chromosome consisting of two sister chromatids (4).

The endoplasmic reticulum (5) and the Golgi complex (6) both have returned to their initial shape and size.

At the end of cytokinesis, the first meiotic division is completed.

Interkinesis

The first and second meiotic divisions are divided by a short resting period (interphase). However, there is no duplication of the chromosomes consisting of two chromatids (no S phase). Both sister chromatids of each chromosome remain connected by the centromeres (7).

Meiotic division II

The second meiotic division occurs just like mitosis (usual nuclear and cell division). It is therefore also referred to as equational division. Since the chromosomes were not duplicated again during the preceding interkinesis, the second meiotic division, which now follows, includes the reduction of the genetic information to the haploid chromosome complement.

Prophase II

Prophase II is mostly like the prophase of mitosis and occurs very quickly in all organisms. The permeability of the cell surface increases to allow the intake of surrounding liquids. The microtubule apparatus of the cytoskeleton is reorganized. The nuclear membrane dissolves and the spindle is built up by rearranging microtubules.

Metaphase II

In metaphase II, the chromosomes are once more arranged at the equator level and the two ends of the spindle are located at the two opposite poles (as in metaphase I). A major difference to metaphase I is that two kinetochores have developed at the sister chromatids which in this case point to opposite pole directions.

9. Anaphase II

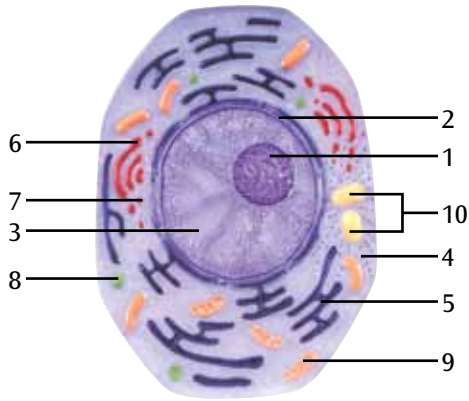
During anaphase II, following now, the two sister chromatids (1) of each chromosome are disjoined just as in mitosis.

The separation begins at the kinetochores (2), the point where the traction fibres of the central spindle are attached. From here, the chromosomes are pulled slowly towards the centrioles (4) located at the cell poles, moving along the microtubules (3) which create a traction effect as they become shorter. The microtubules (5) that are not connected to chromatids now become longer, thus increasing the distance between the centrioles and elongating the cell. At the equator level, the beginning stage of a cleavage furrow (6) becomes visible.

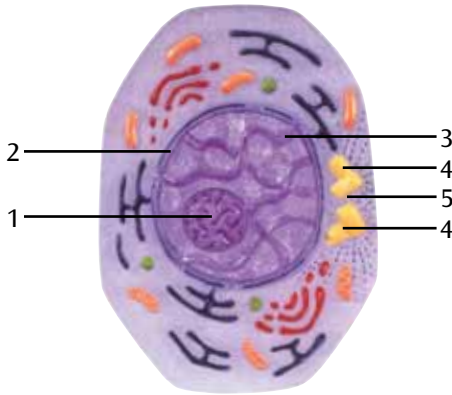
10. Telophase II and Cytokinesis II

The cleavage and division of the two cells produced during the first meiotic division now results in the production of four haploid cells (1) with different genetic combinations resulting from random chromosome distribution and crossing over. This explains why siblings are not identical: one child has more features from the father, the other more from the mother. It is also possible for features of the ancestors to reappear.

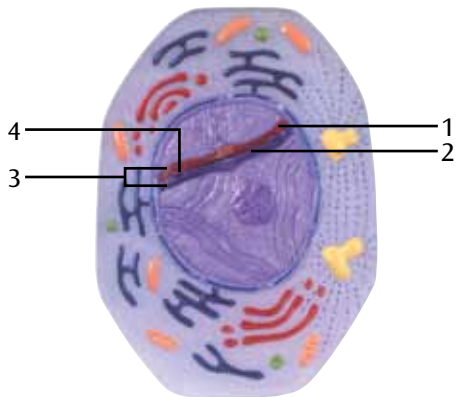
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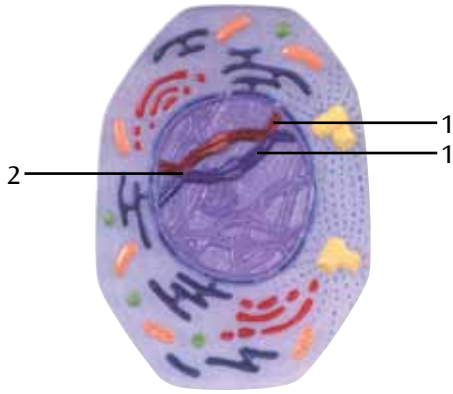
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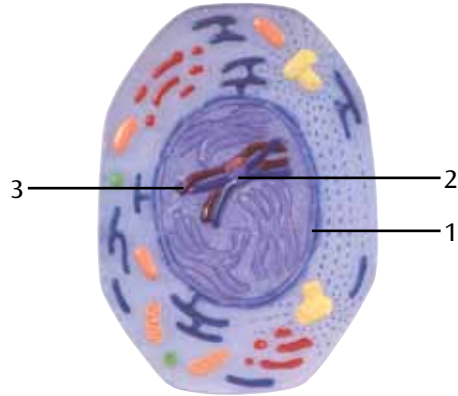
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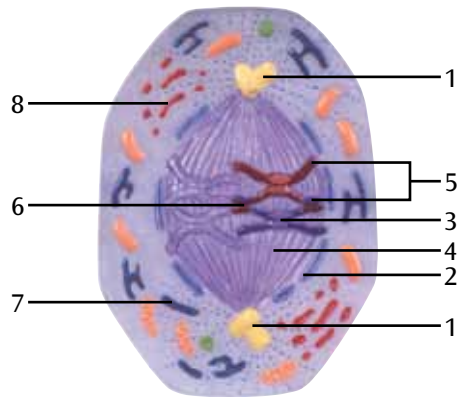
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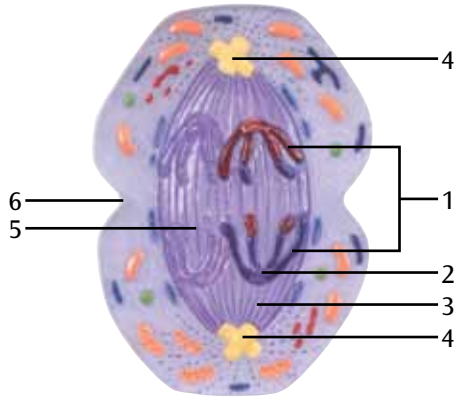
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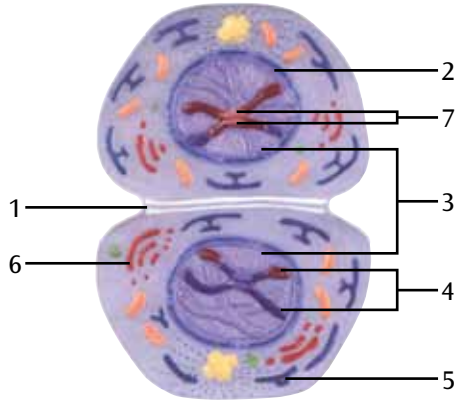
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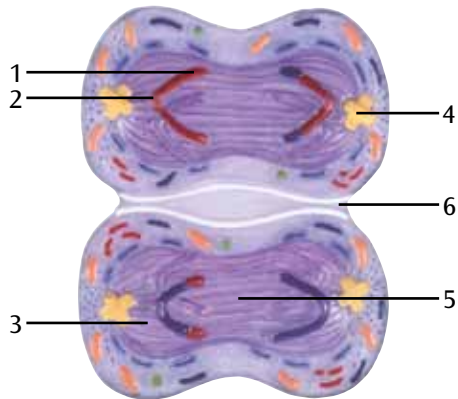
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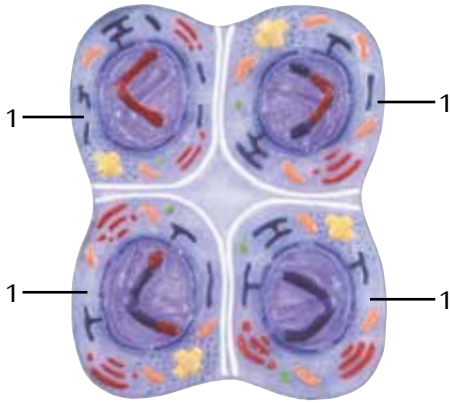
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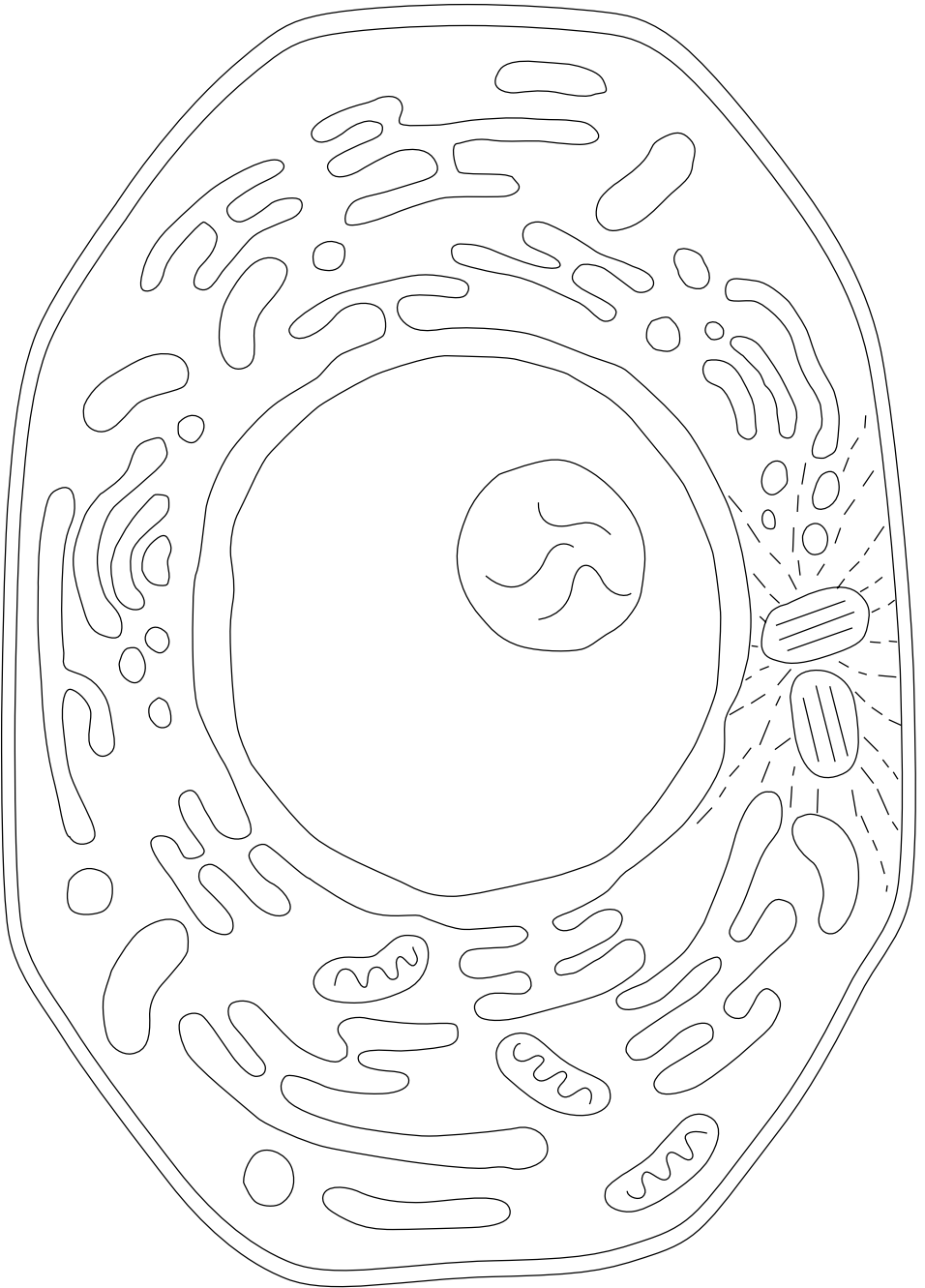


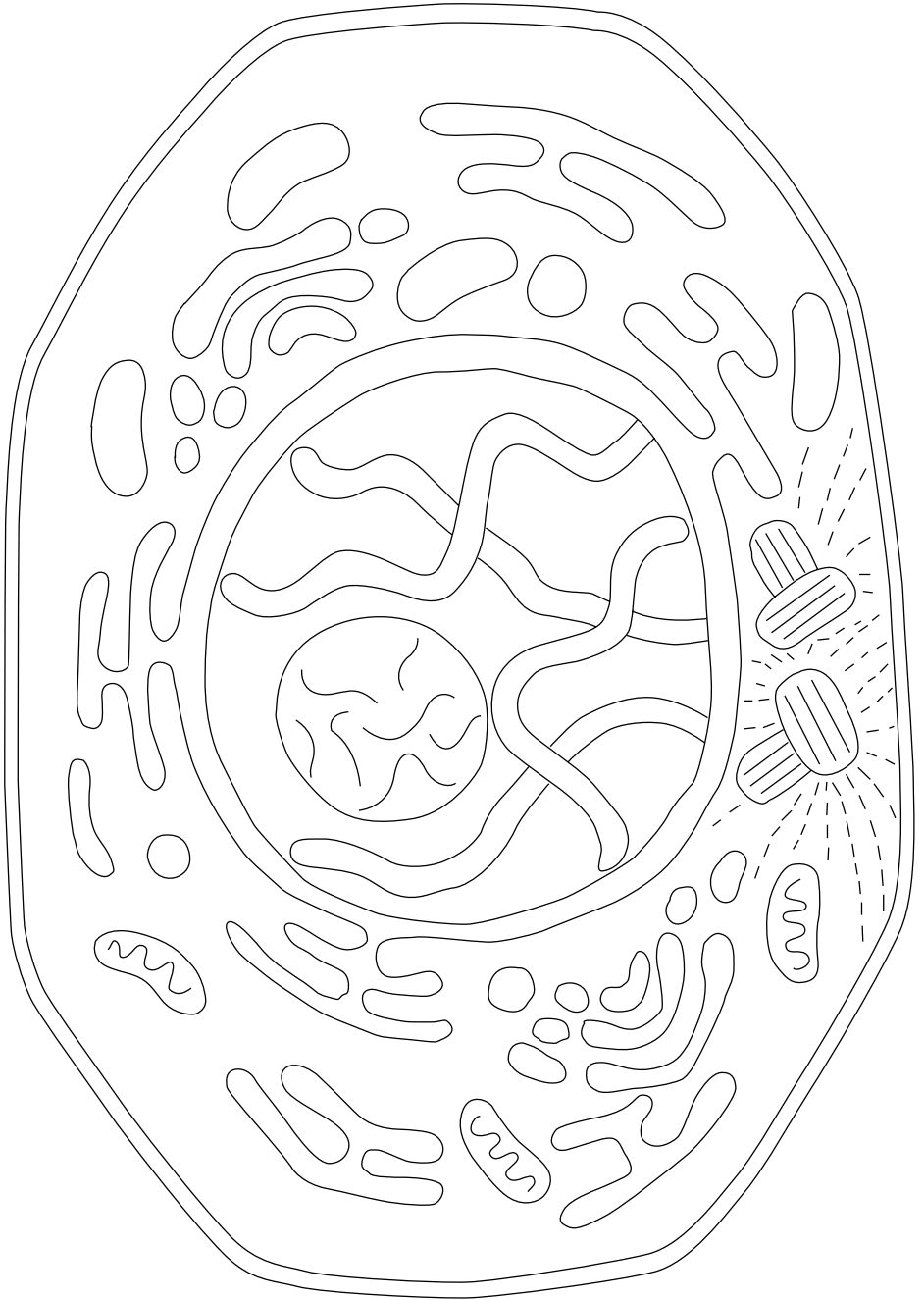
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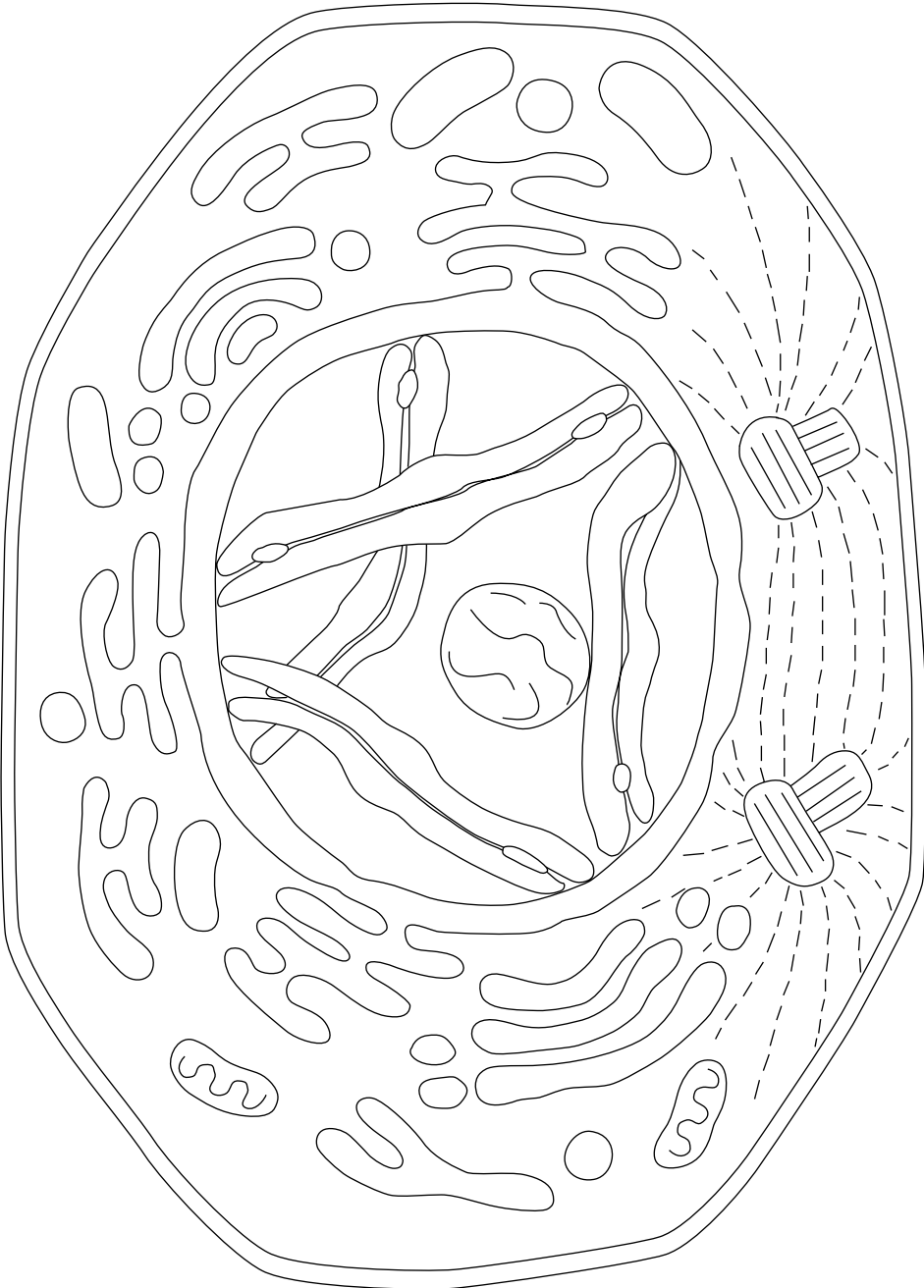


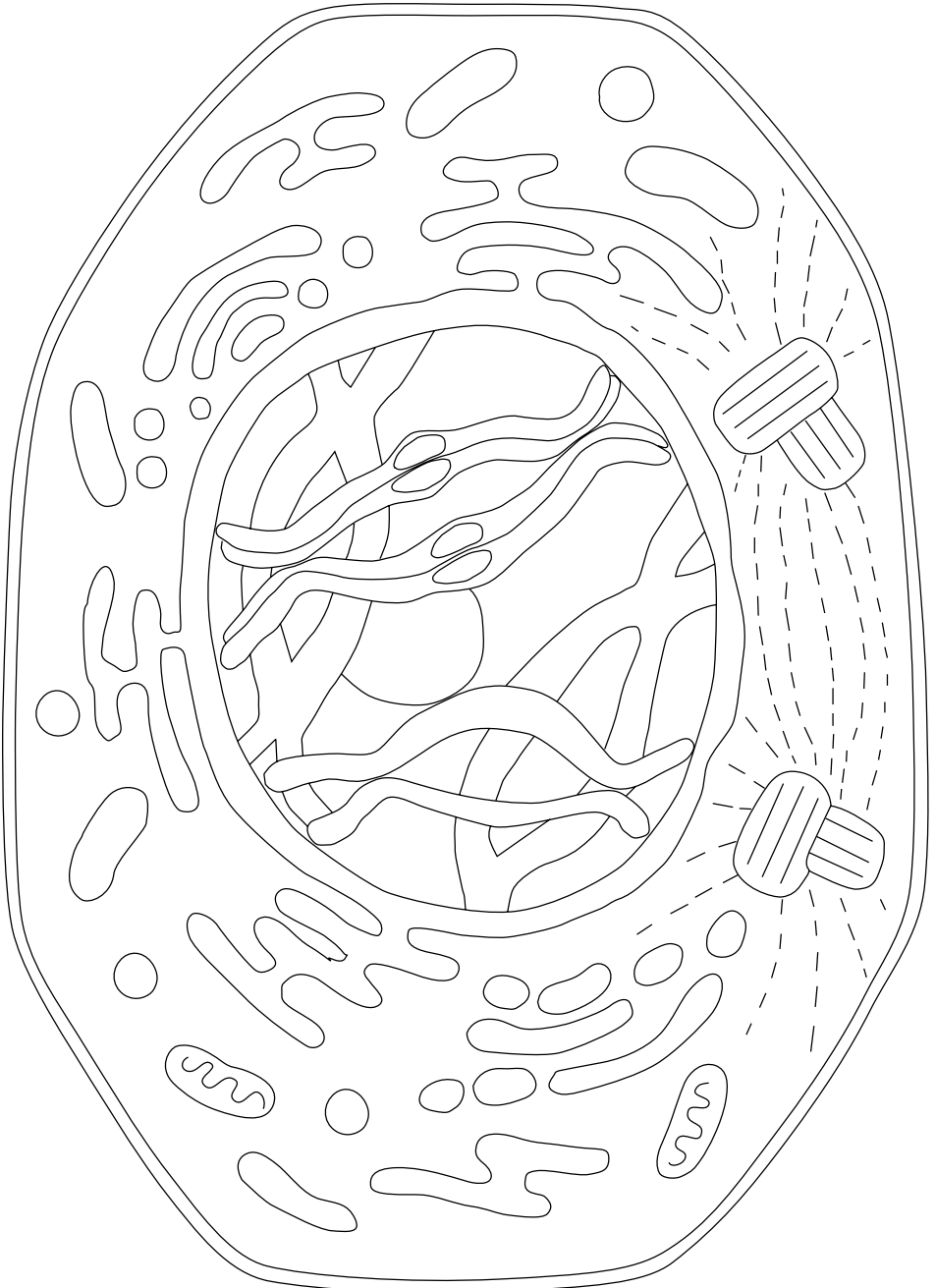
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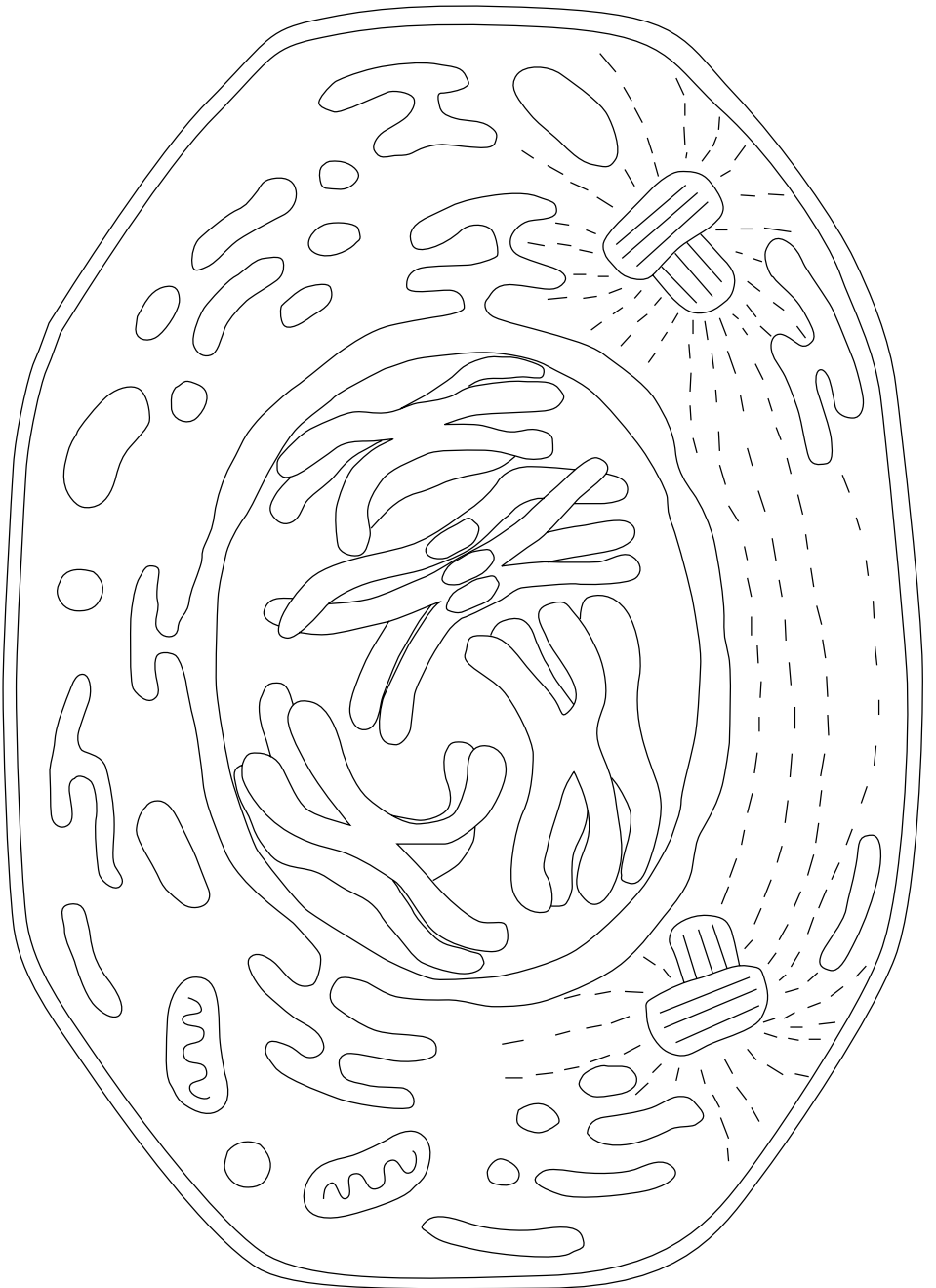


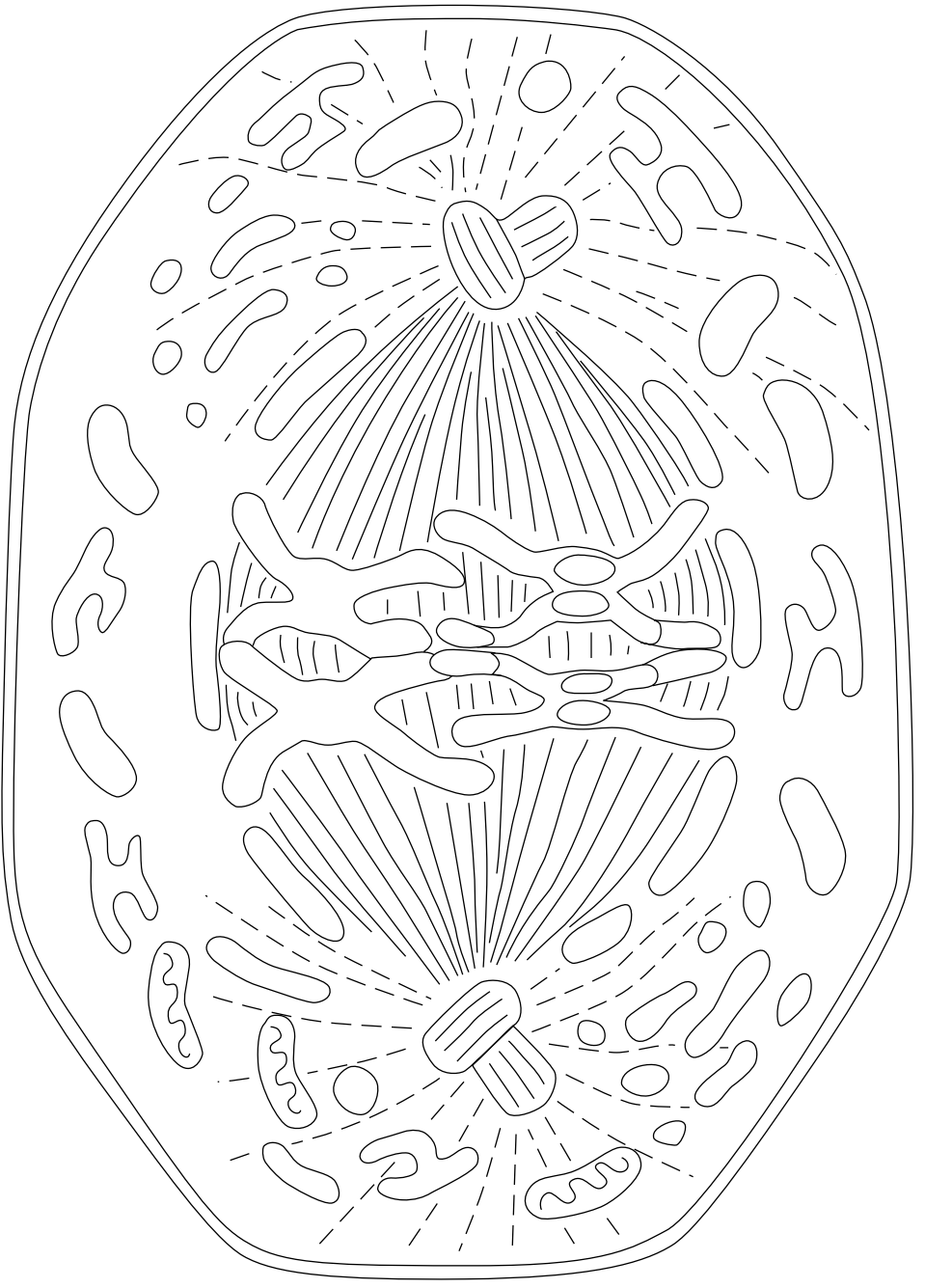


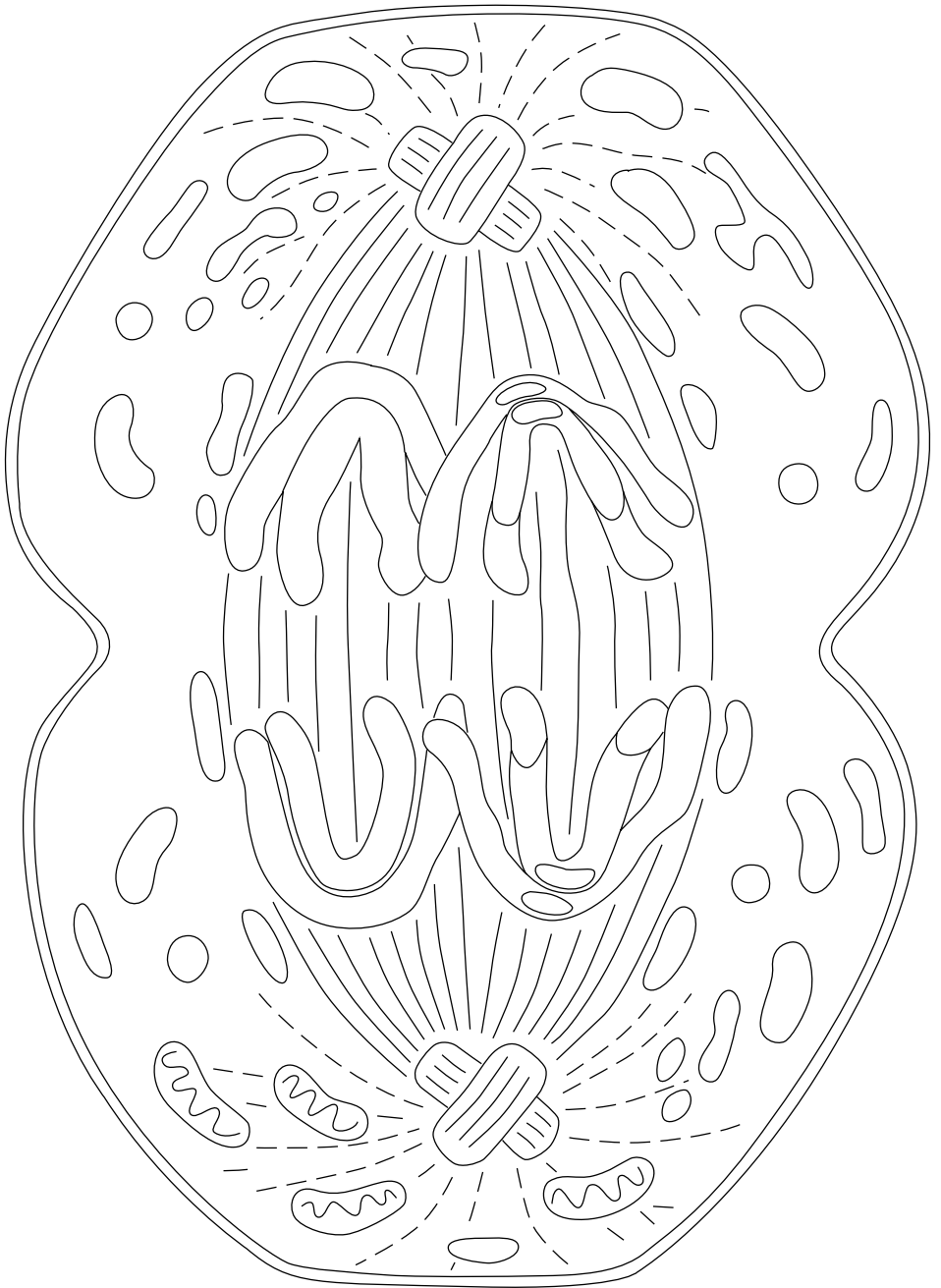


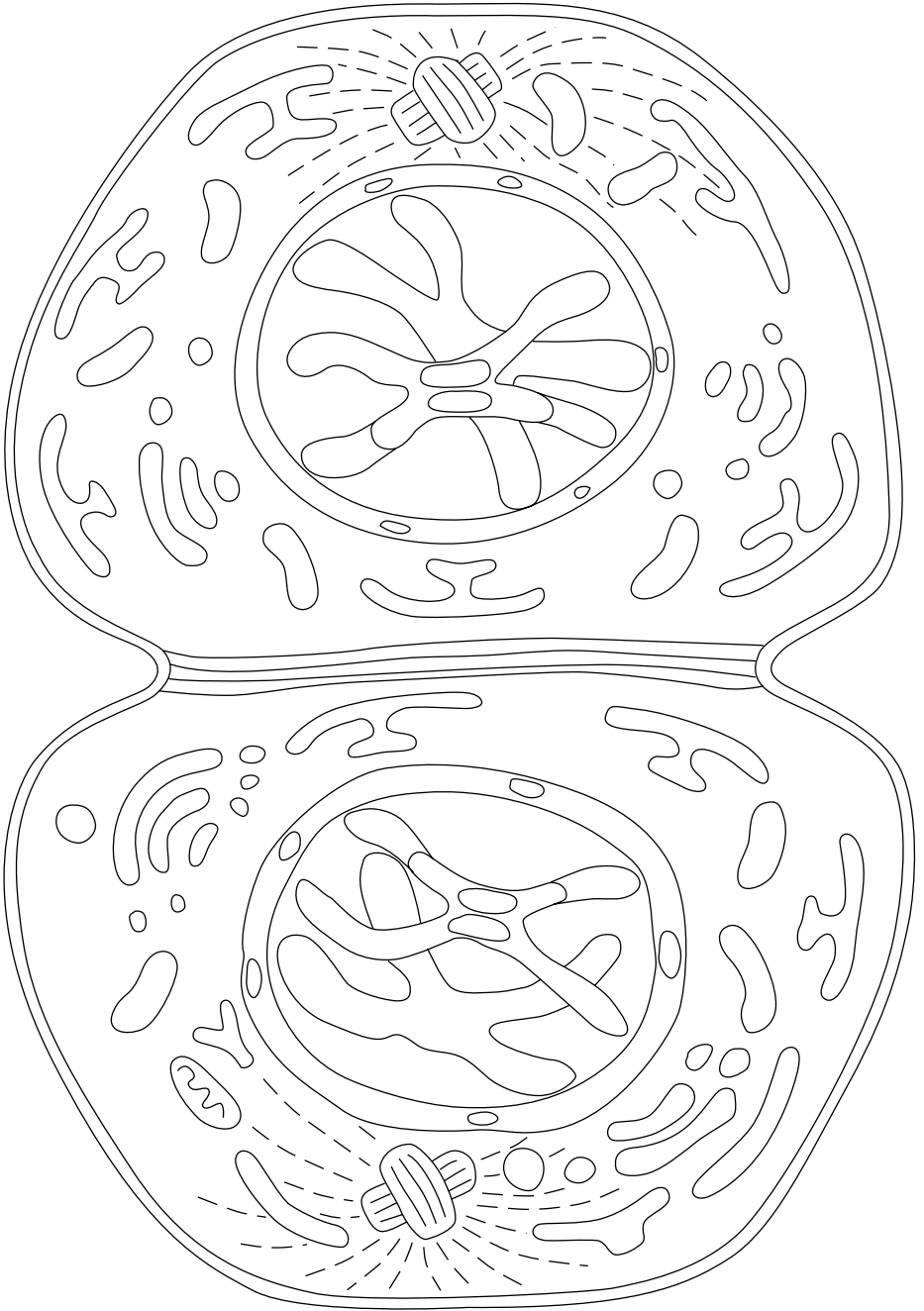


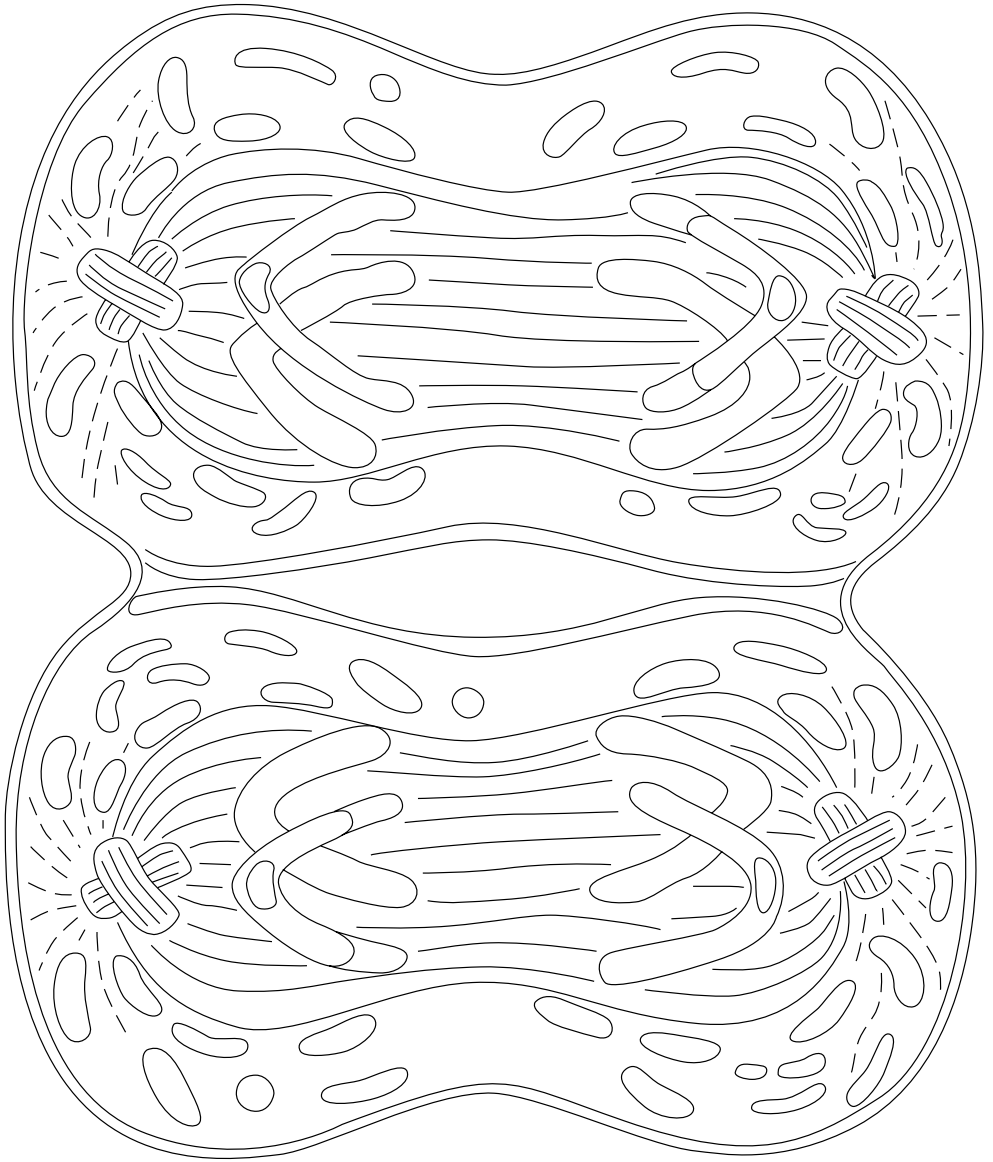


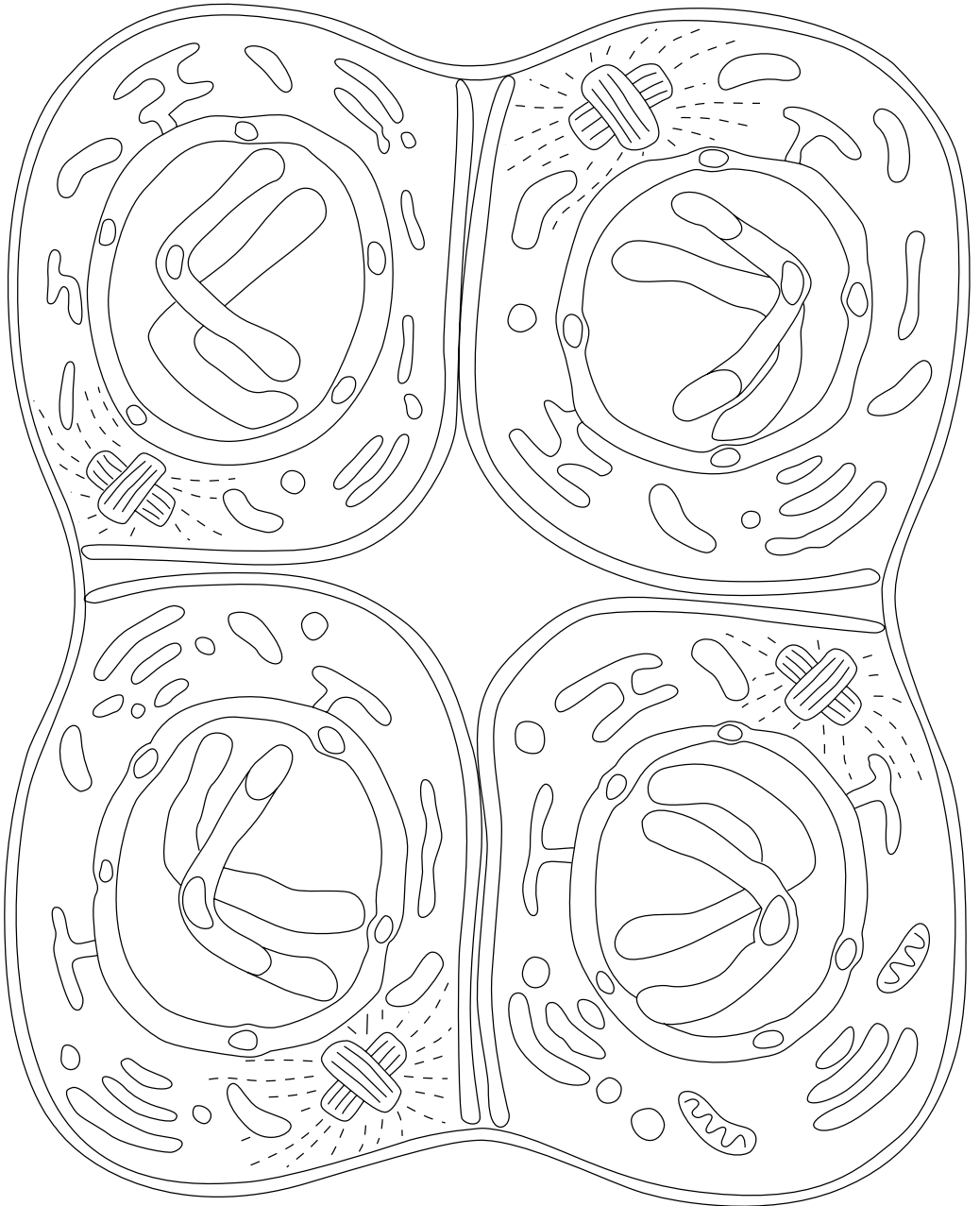












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