Lecture notes – Oct 8; cell division (mitosis and meiosis)

Reproduction: the creation of new individuals from existing ones

Remember **cell theory**, which has three main postulates:
1) Cells are the basic unit of structure and function for all living things,
2) All organims are built from cells, and;
2) all cells arise from other cells.

Thus, if we consider the above conceptual definitions of **reproduction** and **cell theory**, we are led to the unavoidable conclusion that reproduction involves the creation of new cells from preexisting ones – also known as **cell division**.

The characteristics of individual cells, and of multicellular organisms, are coded for in their **DNA.**

What you should know about DNA structure in BIO101 (spoiler alert…not much):
(In this course, we will forego a detailed investigation of DNA structure, because you will do so in BIO103. In fact, we'll forgo a simple investigation…again, you'll hit this hard in BIO103).

DNA (deoxyribonucleic acid): The molecule that stores genetic information that determines the genetic traits (characteristics) of a cell or organism; DNA is the "blueprint for life". (DNA is contained in chromosomes of eukaryotes, which are in the cell nucleus.)

1953: James Watson and Francis Crick (Watson and Crick) describe structure of DNA. (Owing in large part to a now 'famous' X-ray diffraction image generated by Rosalind Franklin.)

1962: Nobel Prize for Watson and Crick (Franklin died in 1958, Nobel is not awarded posthumously)

DNA structure:
DNA is a double-stranded molecule that is helical in shape: a **double helix**

Nucleotides: DNA is a polymer (i.e., long chain) of molecules called **nucleotides** (OMG, this superficiality is painful…but I do not want to repeat what you'll do in BIO103, and we have dragons to slay…). It is the sequence of nucleotides that contains the information from which cells/organisms are constructed. In Bio103, you will learn how the "code" of nucleotide sequences in DNA is "read" by cells and translated into specific proteins/traits.

Gene: Discrete sequence of nucleotides that codes for a particular protein or trait.
(FYI: there are approximately 20,000 genes in the human genome)

Genome – The entirety of an organism's hereditary information

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*****Therefore the essence of reproduction (the creation of new individuals from existing ones) is cell division predicated upon copying the cell's DNA and passing along the copy to the offspring (called the daughter cells – more below). **This is trickier than it sounds!!!**

Why?:

Because (nearly!!) every cell contains the full set of genes (DNA) that codes for every different cell type and function in an entire organism (in addition to a whole BUNCH of leftover genetic "scrap" DNA that is not used (i.e., is not a readable blueprint) but is leftover from eons of evolution). This makes DNA a very long molecule!!! In fact, every cell in the human body contains over 2 meters of DNA!!! WOW!! How the hell can a cell organize, duplicate and partition so much material – and remember – this is crucial material – without accurate copying and distribution the offspring will be mutant!!

Clearly, an **organized process is needed** – and two have arisen for all Eukaryotes:

1) Mitosis The division of a single nucleus into two genetically identical daughter nuclei. Mitosis is the process by which genetic material (DNA) is copied and divided during **asexual** cell division. Cells are diploid ("2n") during all stages of mitosis.

2) Meiosis The division of a single nucleus into four daughter nuclei. These are not genetically identical (stay tuned…more below). Meiosis is the means of cell division that produces **gametes** (eggs and sperm) for **sexual reproduction**. The four gamete cells are all haploid ("1n")

Essential mitosis vocabulary:

Asexual reproduction: The creation of genetically identical offspring by a single parent, without the participation of sperm and egg (gametes…see meiosis vocabulary).

Chromosome – DNA/gene-carrying structure in the nuclei of Eukaryotic cells.

Homologous chromosomes: The two chromosomes that make a matched pair in a diploid (2n) cell ("diploid" and "2n" are defined below). Homologous chromosomes possess genes for the same traits (though they may have different versions of these genes…more on this when we get to genetics). One homologous chromosome is inherited from mom, the other from dad. (For example, humans have 23 different chromosomes, but 2 copies of each and therefore 46 total in each 2n cell.)

Chromatin – the diffuse and threadlike form that all chromosomes are in while cells are in interphase of the cell cycle and are not dividing – for Bio101 this is an unnecessary term that I will NOT ask you to remember.

Chromatid – this, you must know!!! When chromosomes have duplicated but not yet separated, the identical copies are referred to as **sister chromatids**.

Centromere – the constriction at the center of chromosomes / chromatids where the mitotic spindle attaches.

Mitotic spindle – A network of microtubules and associated proteins that move chromosomes during mitosis and meiosis

Haploid – A cell containing a single set of chromosomes (said to be "1n")

Diploid – A cell containing two sets of chromosomes, one from each parent (said to be "2n").

OK, on with the show….

Mitosis

The cell cycle (life cycle of a single cell) is broken into two distinct phases:

1) **Interphase**
2) **Mitotic Phase (mitosis)**

Interphase – The period of the cell cycle in which the cell is performing normal activity and not actively dividing. However, DNA is replicated during interphase. 90% of cell life cycle is interphase.

Mitotic Phase – comprised of 4 stages (for our purposes in Bio101):

1) Prophase – chromosomes thicken inside nucleus, nuclear envelope disintegrates, microtubules of mitotic spindle attach to centromeres on chromosomes (**note** – this "skips" a step presented in the book: *prometaphase*. This is for good reason – you do not need to memorize *prometaphase*).

2) Metaphase – Chromosomes (each with two chromatids) line up in a single row along the metaphase plate

3) Anaphase – Chromosomes pulled apart to opposite poles (sides) of the cell, cell elongates

4) Telophase / cytokinesis– daughter nuclei are formed, spindle atrophies, mitosis concluded**,** cytoplasm of mother cell formally divided in two and the daughter cells now formed (this last step is cytokinesis).

What happens when mitosis goes wrong?

I. Well, mistakes in the physical partitioning of chromosomes is rare as mitosis is a very reliable process (remember, errors in distributing DNA are typically catastrophic and can lead to non-viable daughter cells…). However, **cancer** is a disease of the cell cycle in which mitosis is not properly regulated and cells divide in an uncontrolled manner – forming masses of tissue called **tumors**. Tumors that remain at the site of formation are said to be **benign** and often can be removed surgically. In contrast, malignant tumors break apart **(metastasize,** or undergo **metastasis**). Anti-cancer drugs typically inhibit cell division, an example is **Taxol**. Taxol stops activity of the microtubules. Taxol was originally discovered in the bark of the Pacific Yew (***Taxus brevifolia***) – a conifer from the Pacific Northwest. The problem with chemotherapy drugs is that they impact healthy cells as well as cancer cells. The "Holy Grail" of cancer research is to find a way to deliver the drugs to cancer cells but not healthy cells. Immunotherapy is an emerging technology. Treatment of cancer, and the use of plant products, would make a wonderful topic fro your Review Paper in Bio101.

II. Another type of mistake often occurring during copying of an organisms DNA, but not the physical partitioning of chromosomes during mitosis *per se*, is **mutation**.

Mutation: A change in the nucleotide sequence of an organism's DNA.

As a biologist (this includes you pre-meds students!), you should forever and always be aware of three general types of mutations to DNA (there are more specific types, and you'll learn about them on BIO103):

Deleterious mutation: A mutation that decreases the ability of an organism to survive and/or reproduce.

Beneficial mutation: A mutation that increases the ability of an organism to survive and/or reproduce.

Silent mutation: A mutation that does not change the gene expression…awe shucks, this is such a cool topic…enjoy this in BIO103.

Deleterious mutations occur more frequently, which makes sense because random changes to any set of instructions are most likely to cause the end product to be malformed, misshapen, dysfunctional, etc. Deleterious mutations disappear rapidly in populations due to natural selection (i.e., the organisms that have them have lower S&R and thus die off relatively quickly).

Beneficial mutations are very rare (think about it – a random change to a set of instructions that leads to increased S&R?! – wow!!) and provide genetic variability upon which natural selection can act upon.

Meiosis

The purpose of mitosis is to produce two diploid and genetically identical daughter cells from a single mother cell.

Not so with meiosis!! The purpose of meiosis is to produce four genetically DIFFERENT and HAPLOID daughter cells called **gametes**, one of which can then combine with a haploid cell (gamete) from another individual to produce a new and genetically unique offspring that has a combination of genes from the mother and father. Gametes are the cells in egg and sperm.

So how do we go from 2n to 1n in meiosis. The trick happens during **Metaphase I** – follow along:

Stages of meiosis:

(As with mitosis, DNA is duplicated during the **interphase** stage of the cell cycle)

Meiosis is divided into two larger steps that repeat, these are **meiosis I** and **meiosis II**

Meiosis I

Prophase I: chromosomes thicken and each chromosome, consisting of 2 sister chromatids, are positioned next to the other copy of the same chromosome (homologous chromosomes) where they form a structure called a **tetrad** (root word "tetra", or four, referring to the four sister chromatids). Once tetrads are formed, the tips of the 2 homologous chromosomes can exchange information via **crossing over**. This process is crucial because it increases genetic diversity of the haploid gametes formed during meiosis….keep following…!

Metaphase I: Tetrads align such that chromosomes form two rows instead of the single row as in mitosis – this is the key difference!!!). Mitotic spindle elaborates and attaches to the centromere of each homologous chromosome (sister chromatid pairing).

Anaphase I: Homologous chromosomes (each still comprised of sister chromatids) pulled apart from each other toward opposite poles (sides) of the cell.

Telophase I and cytokinesis: Chromosomes (yes, still comprised of sister chromatids!) arrive at opposites poles of cell and cell is divided – the result is two daughter cells that are 1n but have sister chromatids for each chromosome.

Meiosis II

Essentially, the same process as meiosis I but it starts with haploid cells, crossing over does not occur, and the end result is four haploid cells each with a single copy of each chromosome (no sister chromatids). See book or class notes for details/drawings.

What happens when meiosis goes wrong?

Again, this happens rarely because this process is so vital to producing viable offspring. The most common mishap is that tetrads fail to separate during anaphase I. As a consequence, an entire tetrad is pulled to one pole of the cell rather than separating the homologous chromosomes. This causes an extra copy of a chromosome (or the absence of a copy) in two of the four gametes produced. When such gametes are fertilized, the zygotes rarely survive and are frequently miscarried. When an extra chromosome 21 is produced, however, the zygotes often survive and the condition is referred to as **trisomy 21**, or **Down syndrome**.

Essential meiosis vocabulary (includes mitosis vocab!!)

Sexual reproduction: The creation of genetically unique offspring by the fusion of two haploid sex cells (**gametes**), forming a diploid zygote.

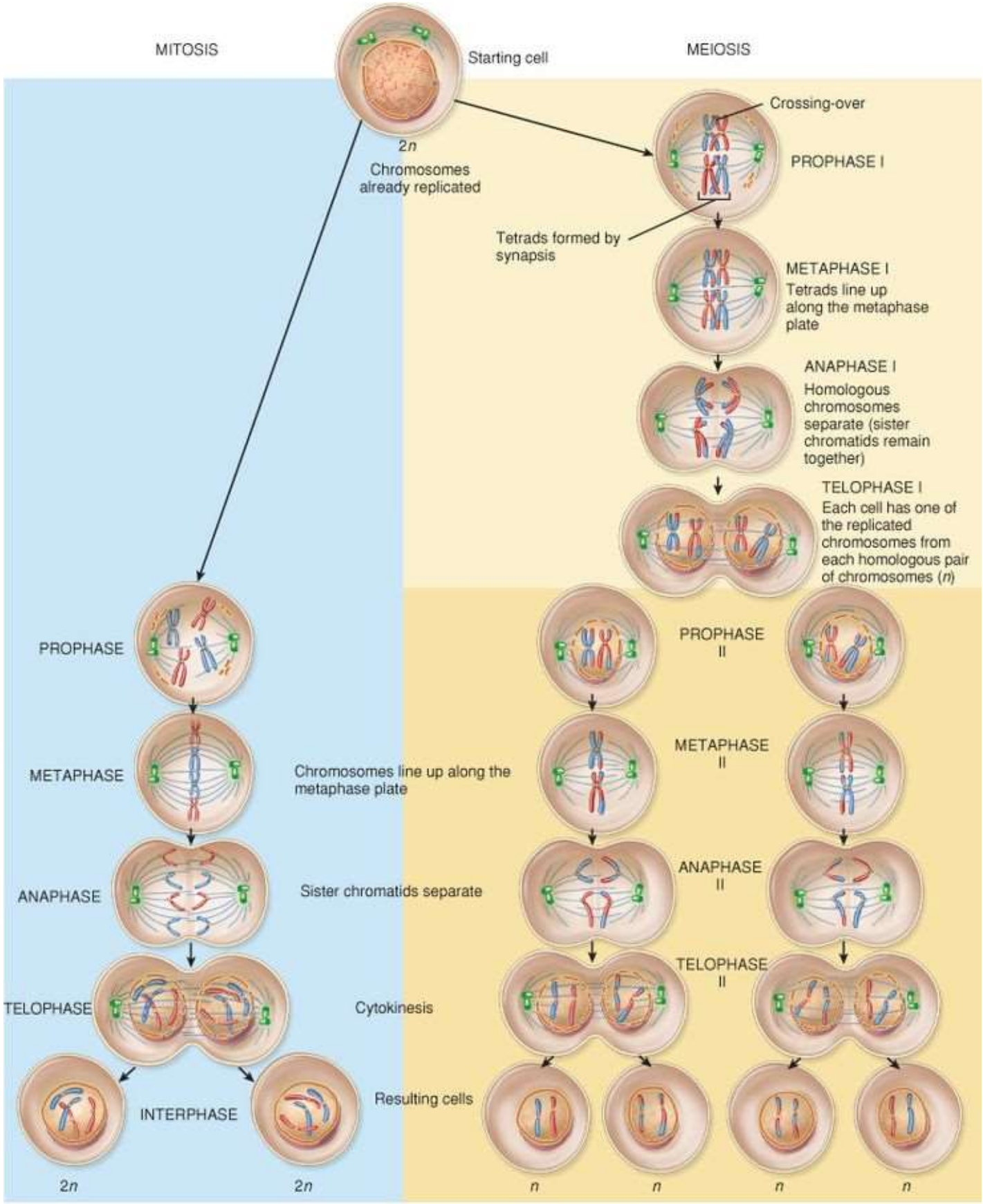
Gamete: a cell that fuses with another cell during fertilization in organisms that reproduce sexually. There are two types of gametes, those produced by males (**sperm)** and those produced by females (**eggs)**.

Haploid: A cell containing a single set of chromosomes (said to be "1n")

Diploid: A cell containing two sets of chromosomes, one from each parent (said to be "2n")

Crossing over: the exchange of genes between homologous chromosomes, resulting in a mixture of parental characteristics in offspring. This can occur between adjacent homologous chromatids during Metaphase I of meiosis when tetrads are paired, and may include 0, 1, or 2 "tips" of the adjacent chromatids.

NEVER FORGET: The purpose of meiosis is to produce four genetically UNIQUE and HAPLOID daughter cells called **gametes** (egg or sperm).


MITOSIS
Starting cell
MEIOSIS
2n
Chromosomes already replicated
Crossing-over
PROPHASE I
Tetrads formed by synapsis
METAPHASE I
Tetrads line up along the metaphase plate
ANAPHASE I
Homologous chromosomes separate (sister chromatids remain together)
TELOPHASE I
Each cell has one of the replicated chromosomes from each homologous pair of chromosomes (n)
PROPHASE
METAPHASE
Chromosomes line up along the metaphase plate
ANAPHASE
Sister chromatids separate
TELOPHASE
Cytokinesis
INTERPHASE
Resulting cells
2n
2n
PROPHASE II
METAPHASE II
ANAPHASE II
TELOPHASE II
n
n
n
n
Somatic cells with diploid number of chromosomes (not replicated)
Gametes with haploid number of chromosomes (not replicated)