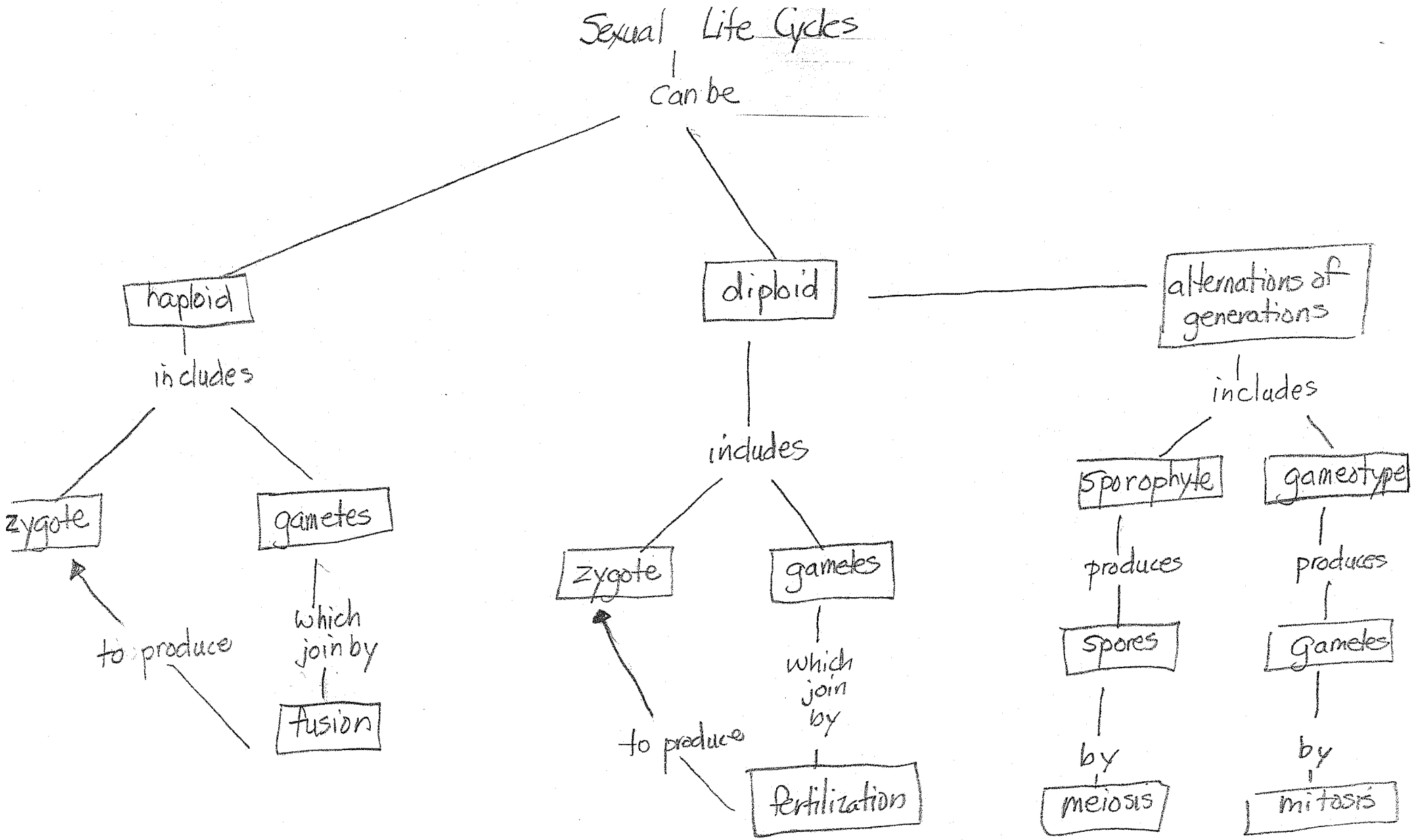
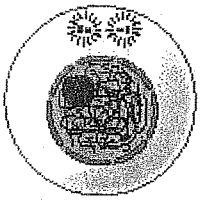
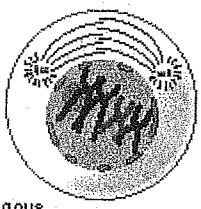

Sexual Life Cycles
can be
haploid
includes
zygote
gametes
to produce
which join by
fusion
diploid
includes
zygote
gametes
to produce
which join by
fertilization
alternations of generations
includes
Sporophyte
gametotype
produces
spores
by
meiosis
produces
Gametes
by
mitosis

Interphase



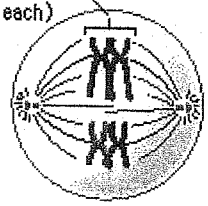
MEIOSIS I

Prophase I
Synapsis and crossing over occur.

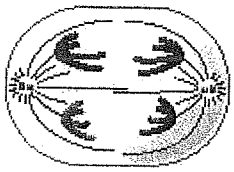


Tetrad (paired homologous chromosomes with two chromatids each)

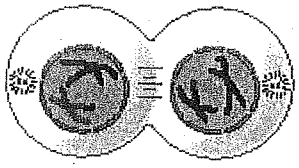
Metaphase I
Tetrads line up on the metaphase plate.



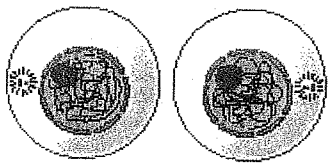
Anaphase I
Homologous pairs separate.



Telophase I



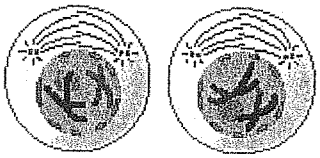
Cytokinesis I



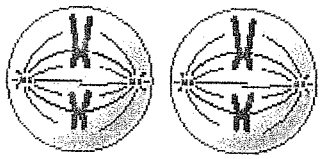
To Prophase II

MEIOSIS II

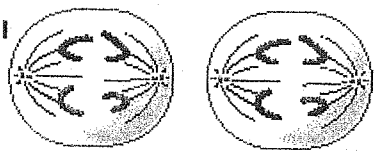
Prophase II



Metaphase II
Chromosomes line up on the metaphase plate.

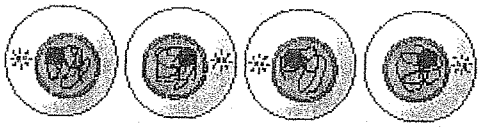


Anaphase II
Sister chromatids separate.



Telophase II

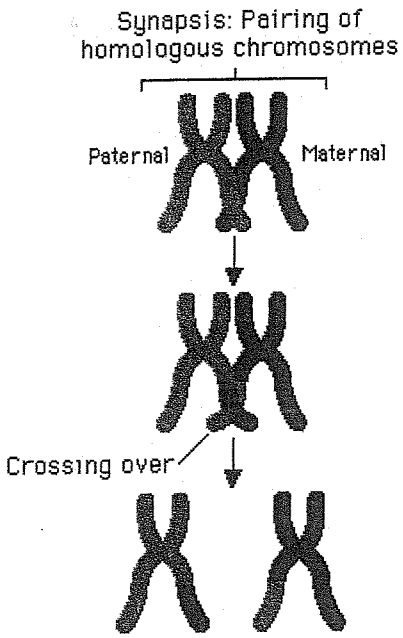
Cytokinesis II



4 haploid daughter cells are formed, each having only one chromosome of each homologous pair.

Crossing Over

Each parent cell has pairs of homologous chromosomes, one homolog from the father and one from the mother. In meiosis, the maternal and paternal chromosomes can be shuffled into the daughter cells in many different combinations (in humans there are 2^{23} possible combinations!). This ensures genetic variation in sexually reproducing organisms. Further genetic variation comes from crossing over, which may occur during prophase I of meiosis.



In prophase I of meiosis, the replicated homologous pair of chromosomes comes together in the process called synapsis, and sections of the chromosomes are exchanged. You can see that after crossing over, the resultant chromosomes are neither entirely maternal nor entirely paternal, but contain genes from both parents. Synapsis and crossing over occur only in meiosis.

Meiosis

Most human cells have 46 chromosomes for a reason, whereas sex cells have half that number – 23. Here's why: The most successful plants and animals have developed a method of shuffling and exchanging genetic information, constantly developing new combinations designed to function better in a changing environment. The process usually involves organisms that have two sets of genetic data, one from each parent.

Through sexual reproduction, a new individual is formed through the union of games (sex cells). But before the union of gametes can happen, the two sets of genetic information present in most cells must be reduced to one. Without this process, the zygote – the cell resulting from the union of two sex cells – would have four sets of chromosomes. Then the next generation, it would have eight, then 16 then 32 – well you get it – it would be a real mess. The resulting organisms would be unable to decode the genetic information, and the final result would be death.

So gametes (cells specialized for sexual reproduction in plants and animals - in animals, eggs in females and sperm in males) have what is known as the *haploid* number of chromosomes. The word comes from the Greek haplos, meaning single. So each gamete contains a single set of chromosomes – 23. When the two gametes unite, they combine their chromosomes (pairs) to reach the full complement of 46 in a normal diploid cell. Logically enough, diploid comes from the Greek diplos, meaning double.

The algebraic equation used to illustrate the relationship between haploid and diploid cells is:

n (haploid) + n = 2n (diploid)

Meiosis, the, is the process that cuts the diploid number in half so that orderly reproduction can take place. It has two major parts, each with mitosis-like phases.

You also need to know that, in human cells, the members of the 23 chromosomes pairs are *homologous*, which means similar but not identical. One member of the pair, for example, may carry the information for black hair, while the other for blond (carry forms of genes for the same traits.) In the human male, meiosis takes place after puberty, when the diploid cells in the testes (male sex organs) undergo meiosis to become haploid. In females, the process begins just a little earlier; in the fetal stage. A series of diploid cells complete only the first part of the process and then migrate to the ovaries, where they wait until puberty. With the onset of puberty, the cells take turns entering meiosis II. Usually, one single egg cell is produced per cycle, although exceptions occur, which, if fertilized, are then called fraternal twins, or triplets, or quadruplets, and so on. The other meiotic cells simply disintegrate.

When a sperm and egg cell – each with 23 chromosomes – unite in fertilization, the diploid condition of the cell is restored. Further divisions by simple mitosis result in a complete human being.

To produce the haploid condition in the gametes, the process of meiosis goes through two divisions, appropriately called meiosis I and meiosis II. Both of these divisions contain stages that are similar to those that occur during mitosis.

Meiosis 1

Prior to meiosis, DNA replication occurs – just as in the case of mitosis – so the gamete has the usual, full wardrobe of 46 chromosomes and 92 chromatids. But not for long

Meiosis is the process of nuclear division in which new combinations of genes are produced. This takes place in two ways: first, meiosis swaps different versions of genes between the maternal and paternal chromosomes of a homologous pair in a diploid cell and second, it sorts the resulting chromosomes into haploid sets containing new chromosomes combinations, which are usually different from those the organism inherited from its parents. After meiosis, fertilization mixes genes up in a third way: two gametes join, uniting their haploid sets of chromosomes into a new diploid combination.

Meiosis I ensures that *each daughter nucleus receives one member of each homologous chromosome pair and each homologue is made of two chromatids*. Meiosis I is often called "reduction division" because it reduces a diploid nucleus to 2 haploid ones, each with half the original number of chromosomes (genetic material).

Prophase I: Many of the processes from prophase are common to this phase. The chromatids coil and thicken to form chromosomes, the nucleoli disappear, the spindle form, and the nuclear membrane disintegrates. But, in meiosis, there is an additional event that is absolutely critical to the process: *synapsis*.

The synapsis process begins when the chromosomes move and lie next to each other (*homologue pairing*). At this point, the associated chromosomes can swap equal amount of DNA in an event called crossing-over. For a while, the chromatids remain joined at the crossover exchange point (*chiasmata*). This swapping of materials results in four completely unique chromatids two pairs of sister chromatids. The new arrangement of four chromatids is called a *tetrad.* (Within each tetrad, corresponding lengths of chromatids are exchanged between non-sister chromosomes in what is called crossing over.)

Metaphase I: During metaphase, the synapsed chromosomes make their way to the center of the cell as single units. Once they get to the equator, their arrangement is really a matter of chance. And the deck of genetic cards is shuffled once again.

Anaphase I: It is during this stage that the chromosomes number is reduced from diploid to haploid. Haploid is reached only after meiosis I. You start with a diploid (2N) cell, then the DNA divides. You are now at a similar starting point as in mitosis, 4N. You then split up the "2N" chromosomes in meiosis I followed by a splitting of these 2N cells to 1N in meiosis I. *Anaphase I begins when the two members of each pair of homologous chromosomes move away from each other and toward the poles of the cell.* Thus, 23 chromosomes end up on one side of the cell and 23 on the other. How do they choose which genetic companions to gather? It is pretty simple, really, it just depends on which side of the equatorial plane they were during metaphase. For obvious reason, this process is called segregation. It is also important to know that there are no bullies in these chromosomal gangs. Each pair of chromosomes makes its own decision about how to segregate, so the process is referred to as independent assortment.

Telophase I: During telophase, the cell takes a step back (or forward, depending on your perspective) to an interphase-like condition. The once tightly coiled chromosomes straighten out, the nuclear membrane re-forms around them, and nucleoli reappear.

Meiosis I is, of course, a throwback to mitosis – any old eukaryotic cell worth its cytoplasm could do these things. The real trick is reduction. Now, in this last stage of meiosis I, *each daughter cell has one member of each homologous chromosome pair*. So, here it is, the key fact we've been leading up to all this time. *Each cell receives one-half of the total number of chromosomes* considered normal for the species, but each cell still has a complete set of genetic material.

Following the exhausting stunts performed during meiosis I, many cells kick back for a while and perform some regular metabolic activities. The one interphase-like activity they avoid at this stage is replication, and for obvious reasons: If the cell were to double its chromosomes number at this stage, all the activity of the previous stages would be for naught. (see section on nondisjunction).

Meiosis II

During meiosis II, the 2 cells continue their dance of division so that – in most cases – four cells are the end result. So, there is a new combination of chromosomes and there are new combinations of chromosomes.

Prophase II: As in both mitosis and Prophase I, the nuclear membrane disintegrates, the nucleoli disappear, and the mechanisms for spindle formation pop into view. The big difference between I and II, however, is that the cells are now haploid rather than diploid. And this time around, the cells avoid synapsis, crossing-over, segregation, and independent assortment. These things are hard work. Once per meiosis is enough.

Metaphase II: Nothing too exciting here. Just as in any old metaphase, the chromosomes attach at their centromeres to spindles and then line up at the equatorial plane. But remember that the pairs of chromosomes are no longer together in the same cell, so each member moves separately.

Anaphase II: In anaphase II, as in the mitosis version of anaphase, the centromeres of the chromosomes actually split in two, with the daughter chromosomes now moving to the poles of the cell. In this phase, they function more like their counterparts in mitosis than those in meiosis I. Because there are no paired homologs at this stage, there is none of the segregation or independent assortment you saw in anaphase I.

Telophase II: The nuclear membrane and nucleoli reappear, the chromosomes with new gene combinations stretch out for the briefest of rests, and the spindles disappear. It's time for cytokinesis. Now there are four – count the, four – haploid cells, where at the beginning of meiosis there was just one diploid (but the ever-essential round of replication just prior to meiosis makes it effectively start at 4N).

The whole point of understanding meiosis is to see how genetic variation occurs. Five factors, described in the preceding section, influence genetic variation in offspring. The following is a more detailed look at crossing-over, segregation, independent assortment, fertilization, and mutations.

Mutations

Several agaents and events can cause damage to the DNA molecule, including s-rays and chemicals like nicotine. When thi damage occurs to the DNA of a sex cell, future generations are affected and mutations can occur. Sometimes, a whole strand of DNA is broken, making it impossible for the cell to synthesize protein properly – or sometimes at all. This problem is called chromosomal mutation, and it is serious stuff. If the damage is bad enough, the cell can die. And if enough cells, die, it's curtains for the whole organism. Worse still is if the cells become immortal and metastatic (spreading), like in cancer, and then kill us.

Crossing-over

At the very beginning of the meiosis process, as the homologous chromosomes come together for synapsis, crossing-over occurs, resulting in a new gene combination and new chances for variety. While the chromosomes are positioned close together, they exchange equivalent portions of chromatids, thus swapping genes. This can happen at a number of different points – or *loci* – on the chromosomes, paving the way for a wide range of genetic variations. Crossing-over is one way of helping to explain how you can have red hair from your mother's father and a prominent chin from her mother. After crossing-over, those 2 genes wound up on a chromosome of your mother's, which she handed down to you.

Segregation

Segregation is the process following crossing-over when the chromosomes separate and move to the poles of the cell. At this point alleles (alternative forms of gene for a specific characteristic) separate, with one daughter cell getting one and the other going to the second daughter cell. For example, an allele on one of the chromosomes might designate five fingers, while the other allele would be for six fingers. These genes now have an equal chance f being transmitted to the next generation. Whether the offspring eventually has five or six fingers will be finally determined by which gene is contributed, along with the allele that comes from the mate during fertilization.

Nondisjunction: Failure of Chromosomes to Separate Properly

Unfortunately, it's not a perfect world. Sometimes a glitch occurs. Remember that in order for the process to work properly, the number of chromosomes in diploid cells has to be reduced to haploid. One of the important occurrences in this process is the segregation of homologous chromosomes into separate cells at the very first meiotic division. Occasionally, a pair of chromosomes finds it just too hard to segregate and they end up in the same gamete.

Nest, two of the final four cells resulting from the meiotic process are missing a chromosomes as well as the genes it carries. This condition usually means the cells are doomed to die. Each of the other two cells has an additional chromosome, with the genetic material it carries. Well, that should be great for these cells, shouldn't it? It should mean they will have an increased chance for genetic variation, and that's a good thing, right?

Wrong – an extra chromosome is like an extra letter from the IRS. It's not something to hope for. Many times, these over-endowed cells simply die, and that is the end of the story. But sometimes they do survive and go on to become sperm or egg cells. The real tragedy than, is when an abnormal cell goes on to unit with abnormal cell. When that happens, the resulting zygote (offspring) has three of one kind of chromosome, rather than the normal two. The term biologist use for this occurrence is *trisomy*.

And here is the real problem – all the cells that develop by mitosis to create the new individual will be trisomic (have that extra chromosome). Now, cells are conformists by nature; they do not deal well with change. A viable female must have two X chromosomes. Too much of some things, even good things, can kill you. And two active X chromosomes in a female with three X chromosomes would kill a potential female, so all women inactivate one of them (randomly) in each cell. The extra X chromosomes is turned into an unexpressed Barr body.

One possible abnormality occurring from an extra chromosome is Down syndrome, a condition that often results in some mental and development impairment and premature aging. Scientists have now pinpointed the chromosome related to Down syndrome – it is chromosome #21. If an ovum with two number 21 chromosomes is fertilized with a normal sperm cell with just one number 21, the resulting offspring has 47 chromosomes (24 + 23= 47), and Down syndrome occurs.

Getting to Know Gametes

Again gametes are sex cells. A sperm is a gamete, and an egg is a gamete. Each egg and sperm contains half the number of chromosomes that are normally present in the whole organism. The, when the gametes join, the organism has all the chromosomes it needs.

Gametogenesis is the process by which gametes form.. The process results haploid cells – either egg or sperm. Haploid refers to the cell having half the number of chromosomes, and it is represented as "N". Diploid is the term for having a full chromosome count – it is written as 2N. for instance, the normal number of chromosomes in each human cell is 46. So, 46 is the diploid, or 2N number. That means that each human egg and each human sperm contain half of 46, or 23 chromosomes (N=23).

The process of gametogenesis is controlled by hormones, those protein-containing substances that start, stop, and alter many metabolic processes.

Spermatogenesis

Sperm are the male gametes. Spermatogenesis is the process that results in the production of haploid sperm cells (spermataogonia). Spermatogonia are cells that contain 46 chromosomes. They are the starting point for spermatogenesis, which occurs in the seminiferous tubules. The spermatogonia line the walls of the seminiferous tubules and go through mitosis. Mitosis is the stage of cell division that replicates a haploid cell. So, each spermatogonium (singular version of thehplural spermatogonia) produce a cell called a primary spermatocyte, which also contains 46 chromosomes.

The primary spermatocyte goes through meiosis. A primary spermatocyte produces two secondary spermatocyte, which contain 23 chromosomes.

Each spermatid develops into a spermatozoa, which is just the technical term for what you know as a sperm. To become a full-fledged sperm the spermatid must mature to the point where it has a tail, middle piece, and a head.

Oognenesis

When a female is a developing embryo, oogenesis begins in the ovaries during prophase I. An oogonium is the initial cell, and it contains all 46 human chromosomes. It grows in size, eventually matuaring into a primary oocyte. The primary oocyte begins going through meiosis, but the process is paused until the female enters puberty, with meiosis I completed as eggs mature after the female reaches sexual maturity.

To prepare for the release of the egg and possible fertilization the primary oocyte continues on through meiosis. The first meiotic division produces a daughter cell (secondary oocyte), which receives most of the cytoplasm (so it is large), and the first polar body (tiny cells), which has minimal cytoplasm (so it is tiny). Both the daughter cell and the polar body contain 23 chromosomes. The second meiotic division results in the daughter cell producing the egg and a second polar body, while the first polar body produces two more polar bodies.

So, out of one original oogonium, only one functional egg is produced. The three polar bodies that also are produced just wither away.

The daughter cell and egg are large, and the polar bodies are small, for a very specific reason. The splitting of the cell – called cytokinesis – is unequal so that the egg ends up full of cytoplasm. The polar bodies basically serve as receptacles for genetic material that is being discarded. Twenty-three chromosomes are in the egg, but the other 23 chromosomes have to end up somewhere. The egg gets most of the cytoplasm so that it can hold plenty of nutrients, as well as the organelles to turn the nutrients into fuel, for a developing embryo. And the secondary oocyte will complete meiosis II when penetrated by sperm.

FYI:

- Chromosomes that are not involved in the determination of gender are called autosomes
- Autosomal chromosomes are present in all cells
- An example of cells that cannot divide once it has differentiated are red blood cells and nerve cells
- Cell centers and centrioles are found at the cell poles of animal cells
- In certain tissues, nuclear division is not followed by cytokinesis. The result in animals – called a syncytium – in plants a coenocyte – is a cell-like unit containing more than one nucleus within a single plasma membrane. This condition may be permanent or only temporary, until cell formation catches up with mitosis.
- In diploid plants, meiosis produces haploid cells called spores.
- If colchicines, a drug that binds to tubulin and interferes with microtubules formation, is applied to a diploid cell in prophase, cell division would be blocked and the chromosome number of the cell would double to tetraploid.