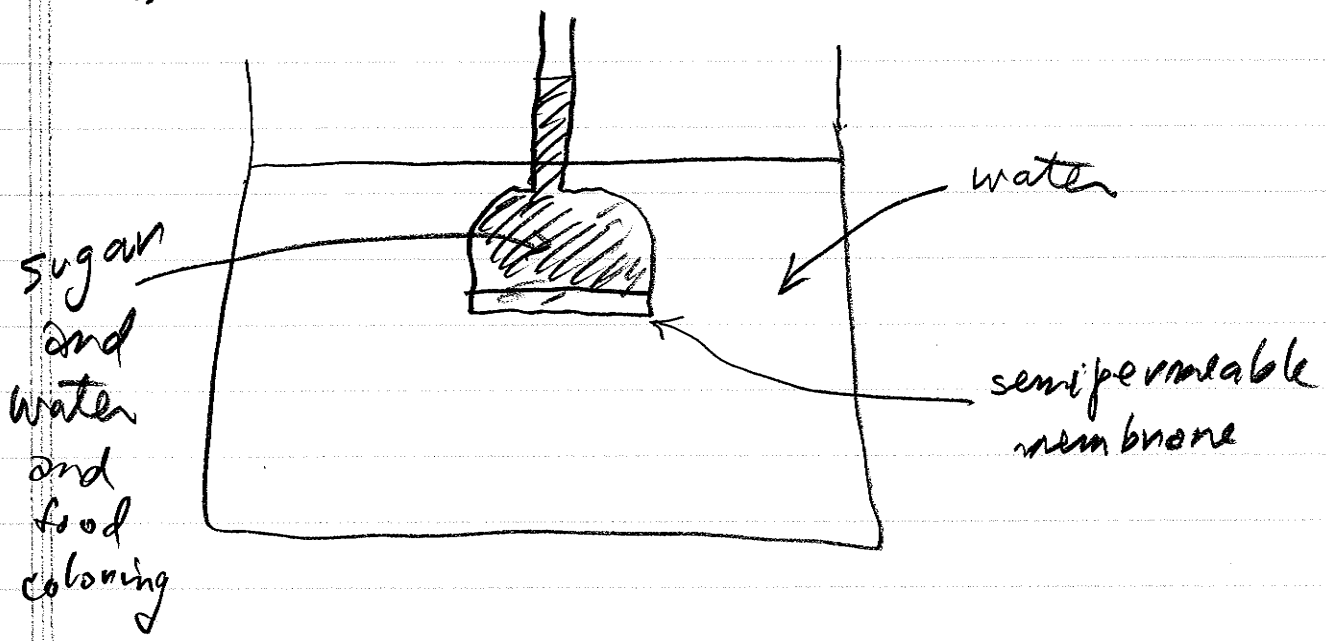
Suppose we put a concentrated solution of sugar in the upside-down bowl of a thistle tube:



The pressure on the left will be $p_L = \frac{N_w}{V} kT = c_w kT$

and that on the right will be

$$p_R = \frac{N_w + N_s}{V} kT = (c_w + c_s) kT$$

so the pressure difference will be

$$\Delta p = c_w kT.$$

We'll use this formula although it holds only for dilute solutions.

A saturated solution of sugar has about 260 g in 100 g of water. The density of water is 1 g/cm^3, while that of sugar is 1.587 g per cm^3. So the volume of the sugar is

$$\frac{260 \text{ g}}{1.587 \text{ g/cm}^3} = 164 \text{ cm}^3$$

and the total volume is $V = 264$ cm^3. Sucrose is $C_{12}H_{22}O_{11}$ with a molecular weight of 342.3. So we have about 260/342 of a mole, and so N_S is

$$N_S = \frac{260}{342} \times 6 \times 10^{23} = 4.6 \times 10^{23}$$

So

$$\Delta p = c_w kT = \frac{N_S}{V} kT = \frac{4.6 \times 10^{23}}{264 \text{ cm}^3} \frac{10^6 \text{ cm}^3}{\text{m}^3} \times 4.1 \times 10^{-21} \text{ J}$$

since $kT = 4.1 \times 10^{-21}$ J.

So

$$\Delta p = 7.1 \times 10^6 \text{ Pa}$$

which is about 70 times atmospheric pressure, which may be too high since saturated solutions are not dilute. But in any case, this is how tall trees get water up to their highest leaves.

Water molecules have big permanent electric dipole moments. So they cling together like magnets. Think of a pot of hot water. A water molecule near the top surface can leave its neighbors and evaporate only if it is moving up fast enough to overcome the dipole-dipole attraction to them. So there's an energy barrier or an activation barrier to escape.

Osmolarity is the molarity times the number of particles per molecule. Table salt, NaCl, in water becomes Na^+ with a cloud of water molecules and Cl^- with a shell of water molecules. So a 1-molar solution of NaCl has an osmolarity of 2. And $MgCl_2$ at one molar has an osmolarity of 3. For dilute solutions, the ideal-gas formula gives

$$p = \left(\sum_i \frac{N_i}{V}\right) kT$$

so each component i contributes to the osmotic pressure.

Red blood cells are fine in saline, but they burst in pure water.

Something about Genetics

The physical properties of an organism are its phenotype. Its genome is its genotype.

An allele is one of a set of alternative forms of a gene.

A haploid cell has one set of chromosomes.

A diploid cell has two sets of similar (homologous) chromosomes and hence two copies of each gene. Most higher organisms are diploid, so they have two alleles of each gene. If the two alleles are the same, then the animal is homozygous; otherwise it is heterozygous.

The vast majority of the cells of an organism are the somatic (or body) cells. These cells divide by mitosis.

Mitosis is the division of the nucleus of a eucaryotic cell. After mitosis, the cell can divide, in a process called cytokinesis. Mitosis & cytokinesis take less than an hour for a mammalian cell. This phase is called M phase.

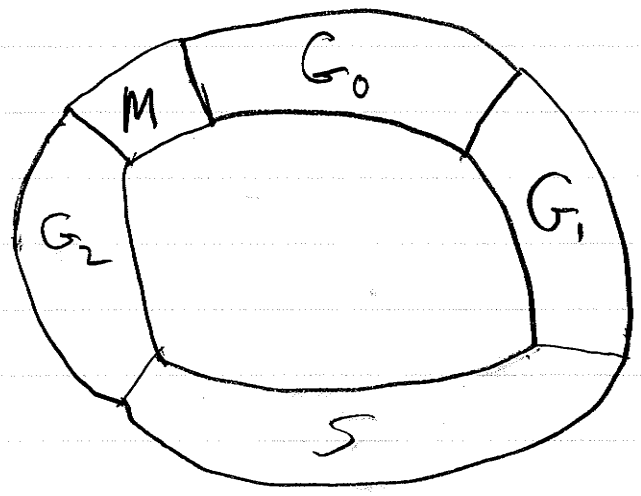
There are four other phases in the cell cycle. A cell can sit in G_0 phase for an indefinite period of time, just living. If it decides to divide, then it enters G_1 phase and starts making enough proteins

and membranes for two cells.

Near the end of G_1 is a commitment point after which the cell is committed to divide.

In <u>S phase</u>, a cell uses DNA polymerase to duplicate its DNA. This takes 10-12 hours in a typical mammalian cell.

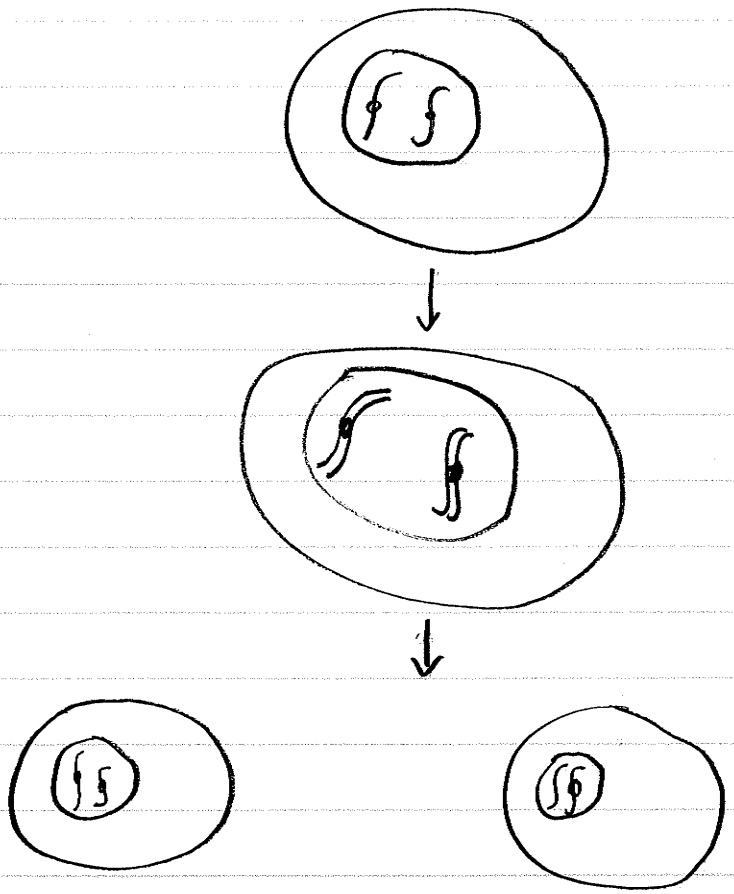
After the DNA is duplicated in S phase, the cell passes in <u>G_2 phase</u> and makes more proteins and membranes, as well as the devices it will use in M phase.

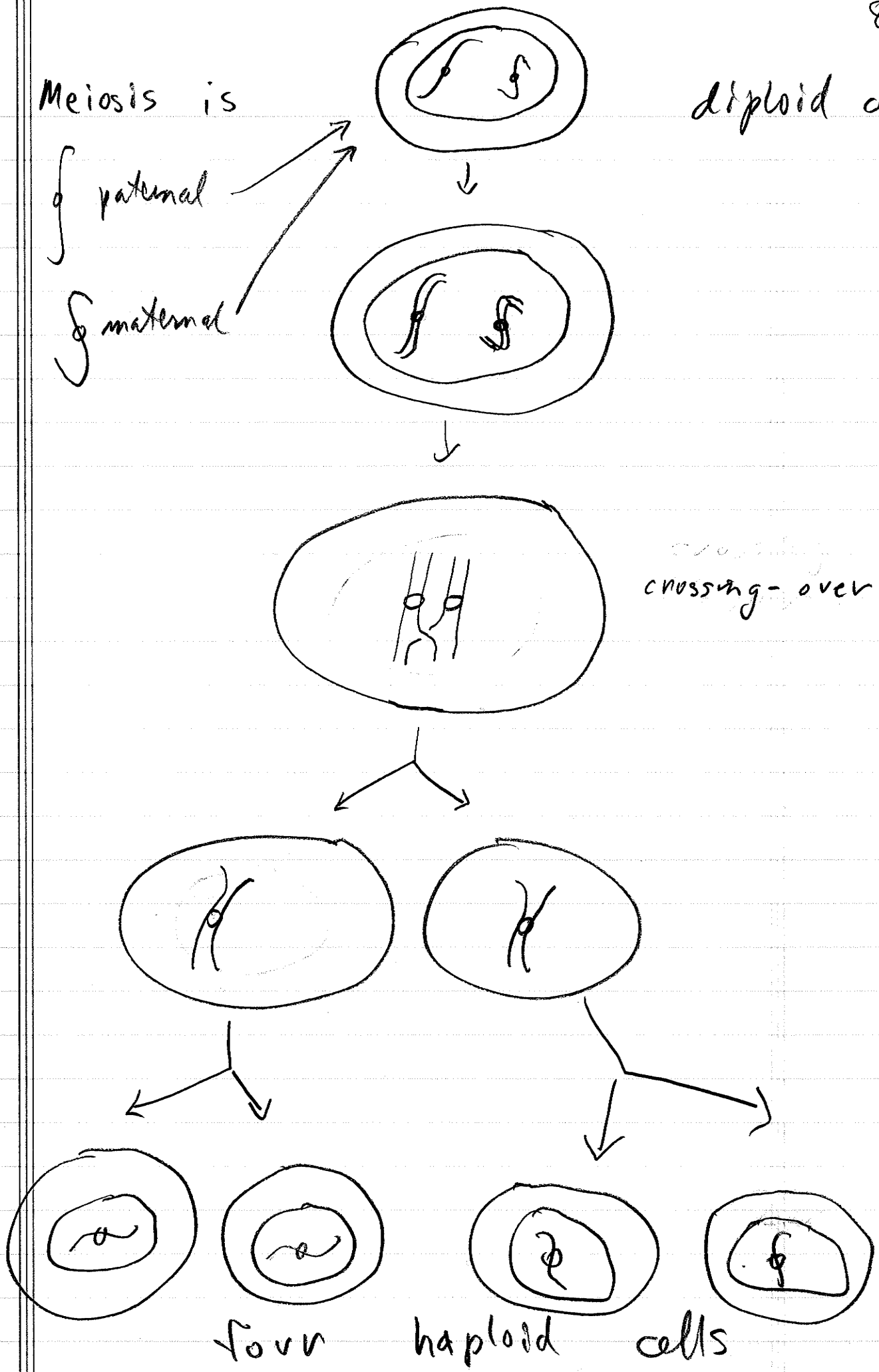


The G_1, S, G_2, M cell cycle takes about one day in mammals.

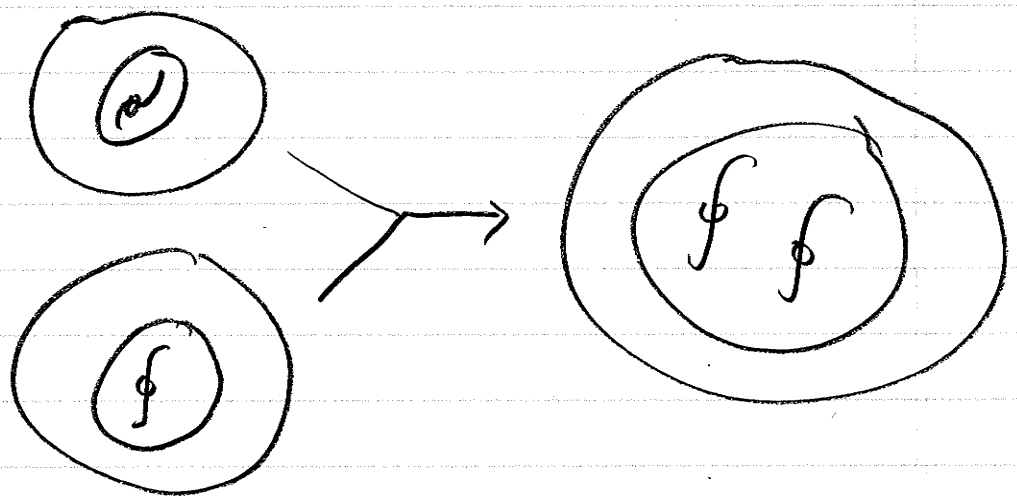
Meiosis is a special type of cell division by which eggs and sperm cells are produced. Meiosis is two successive nuclear divisions with only one round of DNA replication, producing four haploid daughter cells from an initial diploid cell.

So whereas mitosis is "simply"

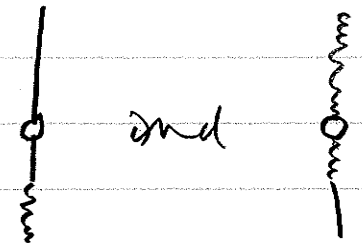



Meiosis is
paternal
maternal
diploid cell
crossing-over
four
haploid
cells

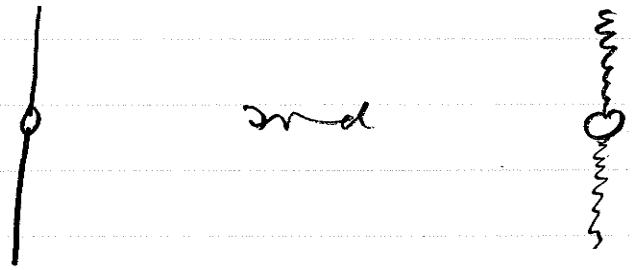
Finally during fertilization, two haploid cells, one an egg, and the other a sperm, combine to form a somatic diploid cell:



The reason for all the effort spent on sex is not to amuse the participants. It is rather that after one crossing-over, the four haploid cells contain two new genomes



as well as the paternal and maternal ones



It is such crossing-over that makes evolution possible in a population of varied genomes. The variation in the genomes of the population arises from crossing-over and from mutations.

Mutations occur because it is very hard to duplicate (replicate) billions of base pairs of DNA without making a single error.

Remarkably, the error rate, at least in eucaryotic cells, is only 1 per 10^9 nucleotide base pairs. See pages 238 - 254 of MBoC4 for the details.

The error rate in RNA synthesis and in the translation of RNA into protein is 1 part in 10^4. So RNA viruses, like HIV and flu, mutate rapidly.

UV radiation can cause mutations because a single ultraviolet photon has an energy $h\nu = h\frac{c}{\lambda}$

in which $c = 3 \times 10^8$ m/s and $h = 6.6 \times 10^{-34}$ Js is Planck's constant.

UV radiation has $1 < \lambda < 400$ nm.

So a UV photon has energy

$$E = h\nu = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}\ J\,m}{\lambda}$$

$$= 2 \times 10^{-25}\ \frac{J\,m}{\lambda}$$

If $\lambda = 400\ nm = 400 \times 10^{-9}\ m = 4 \times 10^{-7}\ m$,

then

$$E_{400} = \frac{2 \times 10^{-25}\ J\,m}{4 \times 10^{-7}\ m} = \frac{1}{2} \times 10^{-18}\ J$$

$$= 5 \times 10^{-19}\ J$$

$$= 5 \times 10^{-19}\ J \times \left(\frac{1\ eV}{1.6 \times 10^{-19}\ J} \right)$$

$$= \frac{5}{1.6}\ eV = 3.1\ eV$$

which is not quite enough to break

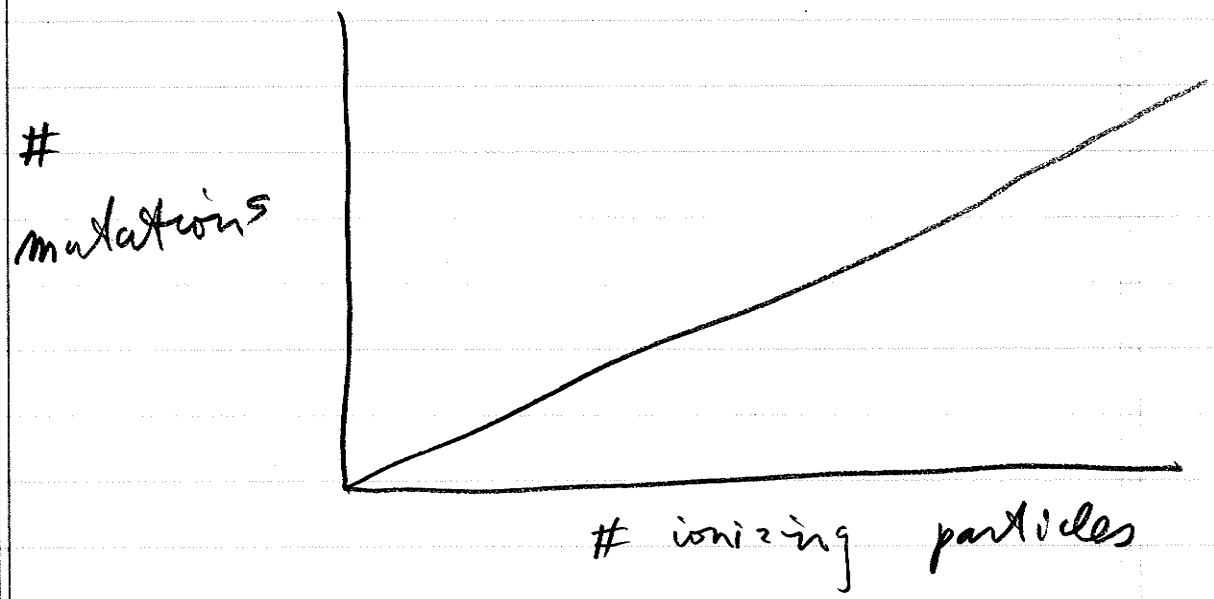
most covalent bonds. But a photon with $\lambda = 40$ nm has 10 times as much energy or

$E_{40} = 31$ eV

which can break any covalent bond I know of.

A charged particle such as an electron or a proton moving at a high speed can also break a covalent bond. Fast charged particles often knock electrons out of molecules and so are called "ionizing radiation." About 10 eV is the lower limit for ionizing radiation.

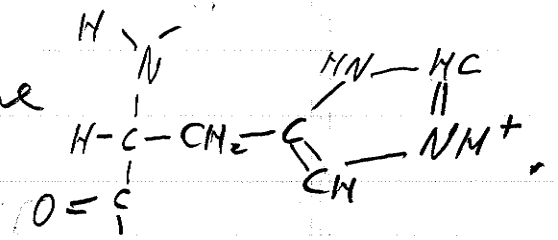
Because a single particle of more than 10 eV or so can break a covalent bond, the mutation rate is linear with the dosage



Healthy cells often can repair the mutations induced by UV radiation. Amazingly, molecular devices inside cells use the energy of UV photons to power their repair of DNA that has been damaged by other UV photons!

A diploid cell has two copies of most of its genes. When these alleles are identical, the cell is a homozygote. When the alleles differ, the cell is a heterozygote.

Some mutations are silent. For instance, because the genetic code uses 64 triplets of bases to code for 20 amino acids and for the start and stop codons, many mutated triplets code for the same amino acids. For example, AGA, AGG, CGA, CGC, CGG, and CGU all code for the amino acid arginine



Some mutations are lethal.

Some are effective but innocent.

Some cause diseases. As cells and animals evolved, each mutation that cause diseases became rare or recessive. An animal that has one healthy copy of a gene (<u>wild type</u>) and one recessive, disease-causing copy of the gene, will be healthy. But if two such animals breed, some of their offspring will be homozygous in the recessive gene and so will be sick. This is why it's illegal to marry brothers with sisters.

It is possible and legal to interbreed mice, however, and some companies have produced strains of mice that have nearly identical genomes. As long as their common genome lacks disease-causing genes, these mice are healthy — until they are consumed in experiments.

Because of epigenetic and environmental factors, purebred mice are not identical. But the descendants of any two pairs of mice will display the same distribution of phenotypical properties — heights, colors, weights, etc.