**Extranuclear inheritance**

1. All genetic loci discussed to date have been located on the chromosomes in the cell's nucleus
2. Maternal inheritance of leaf color in 4 o'clocks (Correns 1908)
A. All progeny are like the female parent (maternal inheritance)
B. This trait is controlled by a genetic factor that are outside the nucleus (possibly in the chloroplast)
3. Definitions of maternal inheritance, extranuclear inheritance, and cytoplasmic inheritance
	1. Inheritance of pyrenoids in chloroplasts of *Spirogyra triformus* by VanWisselingh (1920)
	A. *Spirogyra*2 chloroplasts in each cell
	B. VanWisslingh found a cell in which one chloroplast had pyrenoids and the other chloroplast did not have pyrenoids
	C. When this cell divided, both daughter cells were like the mother cell.
	D. Genes in the nucleus couldn't have caused this because both chloroplasts would have been the same
	     Genes in the cytoplasm outside of the chloroplast couldn't have caused this because both
	         chloroplasts are in the same cytoplasm and would be the same
	     This could only be caused by a genes in the chloroplast itself.   This work proved that genes are
	         present in the chloroplasts themselves which control the phenotype of chloroplasts.
4. Genes in the nucleus also control the phenotype of chloroplasts
A. There are hundreds of known genes located on chromosomes that control the phenotype of chloroplasts
B. Example, albino gene in maize.
5. Poky mutation in *Neurospora crassa*(bread mold, Mitchell and Mitchell, 1952)
A. Poky *Neurospora* are slow-growing because they lack many mitochondrial enzymes
B. There is maternal inheritance of the poky phenotype
C. Thus, a gene that controls the mitochondrial phenotype is in the cytoplasm, possibly in the mitochondria
D. In 1965, the mitochondria were isolated from poky *Neurospora*.  These were injected into normal cells and
        the cells became poky.   This proved that the gene for poky is in the mitochondria themselves
6. Petite mutations in *Saccharomyces cerevisiae*(baker's and brewer's yeast, Ephrussi et al., 1956)
A. Petite yeast produce small colonies because they are unable to carry out aerobic respiration because they have defective mitochondria
B. Segregational petites are due to genes in the nucleus
C. Neutral and suppressive petites are due to genes in the cytoplasm
D. Thus, there are genes in the nucleus and also in the cytoplasm that control the phenotype of the mitochondria
7. Genetic information is present in chloroplasts and mitochondria
A. DNA was shown to be  present in chloroplasts (1963) and in mitochondria (1964)
B. Chloroplasts and mitochondria have complete transcriptional and translational apparatuses
C. The complete nucleotide sequence of human mitochondrial DNA has been determined (16,569 nucleotides)
    1) Human mitochondrial DNA codes for 13 proteins, 22 tRNAs, and 2 rRNAs.
    2) The complete nucleotide sequences have been determined for mitochondria and chloroplasts of many other organisms
D. Coding capabilities of chloroplasts
    1) Mitochondria have hundreds of proteins, but only a small number (13 in humans) are coded for by the mitochondrial genome
    2) Most proteins in mitochondria are coded for by the nuclear genome, translated on cytoplasmic ribosomes, and imported into the mitochondria
8. Evolution of eukaryotic cells (endosymbiont hypothesis) (the hypothesis that is most widely accepted)
A. An endosymbiont is a symbiont that is present inside a cell
B. Anaerobic prokaryotes were thought to be the first living things on earth
C. Anaerobic prokaryotes evolved into aerobic prokaryotes
D. The oxygen released by aerobic prokaryotes was toxic to the anaerobic prokaryotes, and this presumably was the driving force that caused anaerobic prokaryotes to evolve into aerobic prokaryotes
E. Anaerobic prokaryotes evolved into anaerobic eukaryotes
F. The anaerobic eukaryotes took up aerobic prokaryotes as an endosymbiont, and the aerobic prokaryotes became mitochondria
G. These cells then took up photosynthetic prokaryotes as an endosymbiont, and the photosynthetic prokaryotes became chloroplasts
H. Most of the genes of the original endosymbionts were lost because the same types of genes were present in the nucleus of the host eukaryotic cell.  For this reason, the genomes of mitochondria and chloroplasts are much smaller than prokaryotic genomes.
9. Cytoplasmic male sterility (CMS), a cytoplasmic mutation that is extremely important for agriculture
A. CMS plants are male-sterile and female-fertile.
B. These mutations are in the mitochondria and are maternally inherited
C. How CMS is used in the production of hybrid corn seed was discussed.
10. Infectious heredity, an invading microorganism causes a mutant phenotype that is then transmitted by maternal inheritance