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Introduction to Biomedical Science

(Module for MSc Health Data Analytics and Machine Learning at Imperial College London)

Sonja N. Tang, MSc

(sonja.tang19@imperial.ac.uk)

What's the structure of this module?

- 5 sessions x 1.5 hrs:

Intro to Biomedical science

- Molecules of life I
  - Atoms and periodicity
  - Carbon
  - Water
  - Carbohydrates
  - Lipids
  - Proteins
- Molecules of life II
  - Nucleic acids
  - DNA and RNA
  - Heredity and genetics
- Cells
  - Cell theory
  - Ultrastructure
  - Cell cycle
  - Mitosis
  - Meiosis
- The central dogma I
  - The central dogma
  - Transcription
  - Translation
  - Mutations
- The central dogma II
  - Gene regulation
  - OMICs Technologies

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Introduction to Biomedical Science - 1st Session: Molecules of Life I

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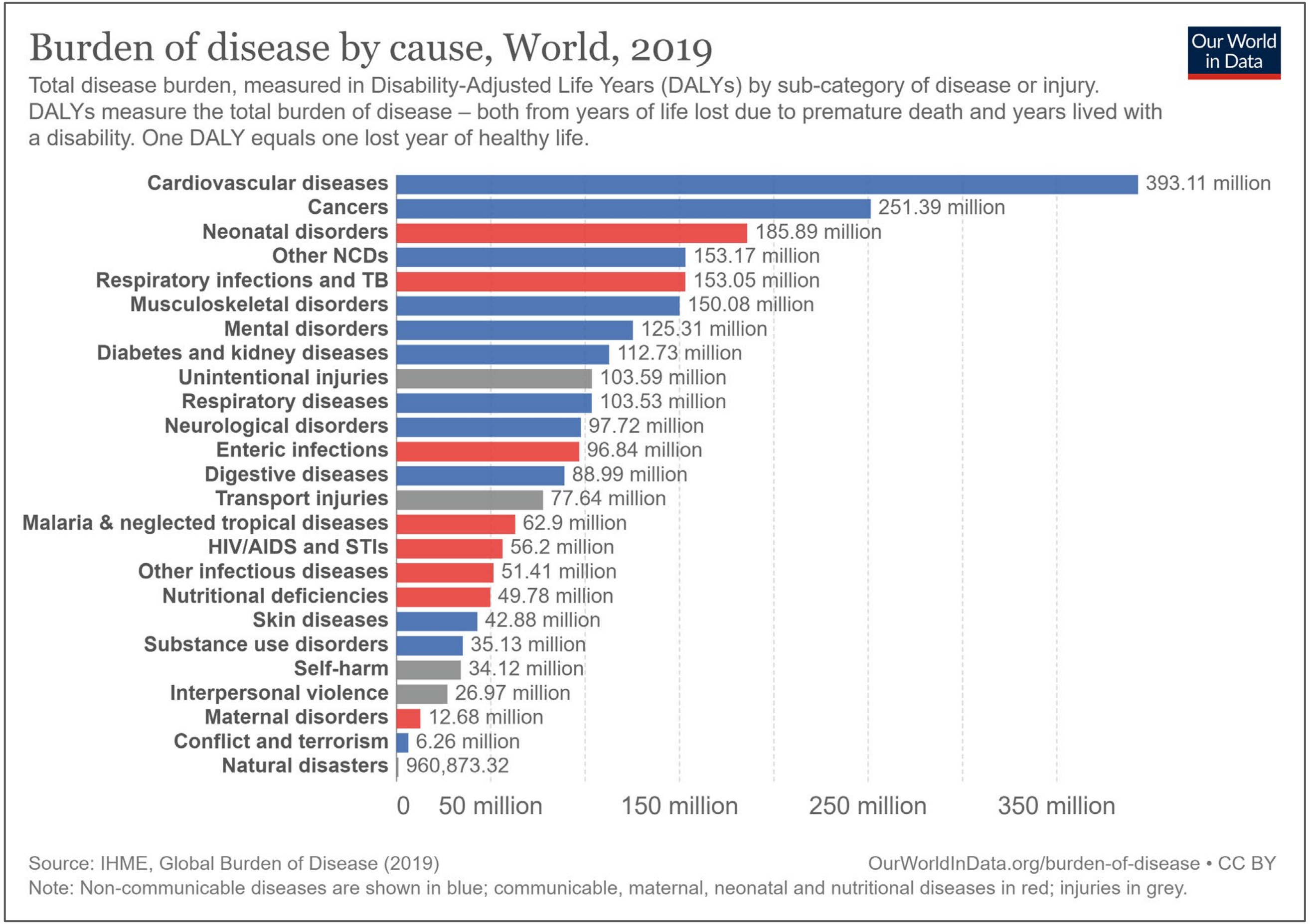
Rationale



Burden of disease quantifies both mortality and morbidity.

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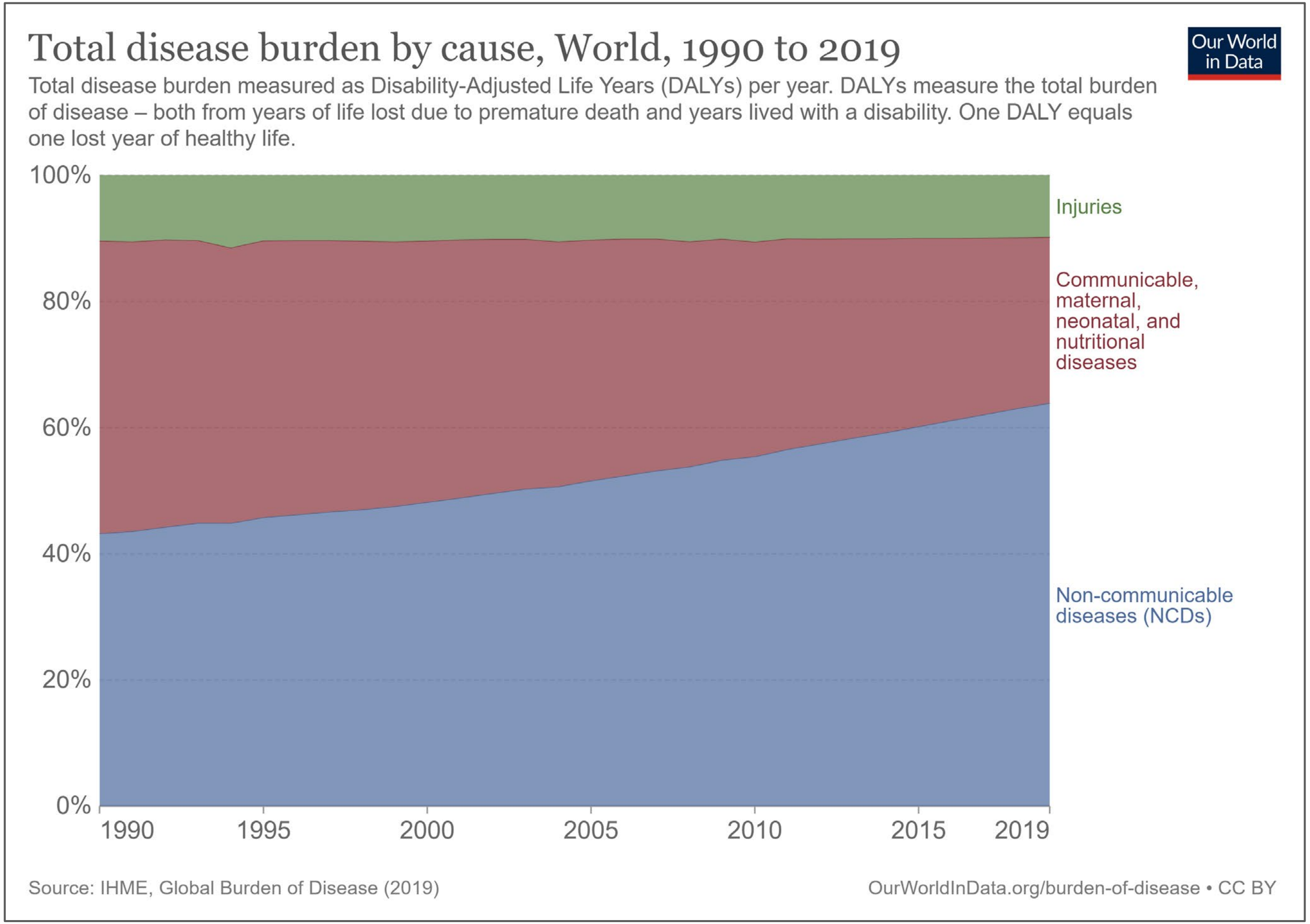
Rationale



The share of non-communicable diseases causing burden of disease is growing.

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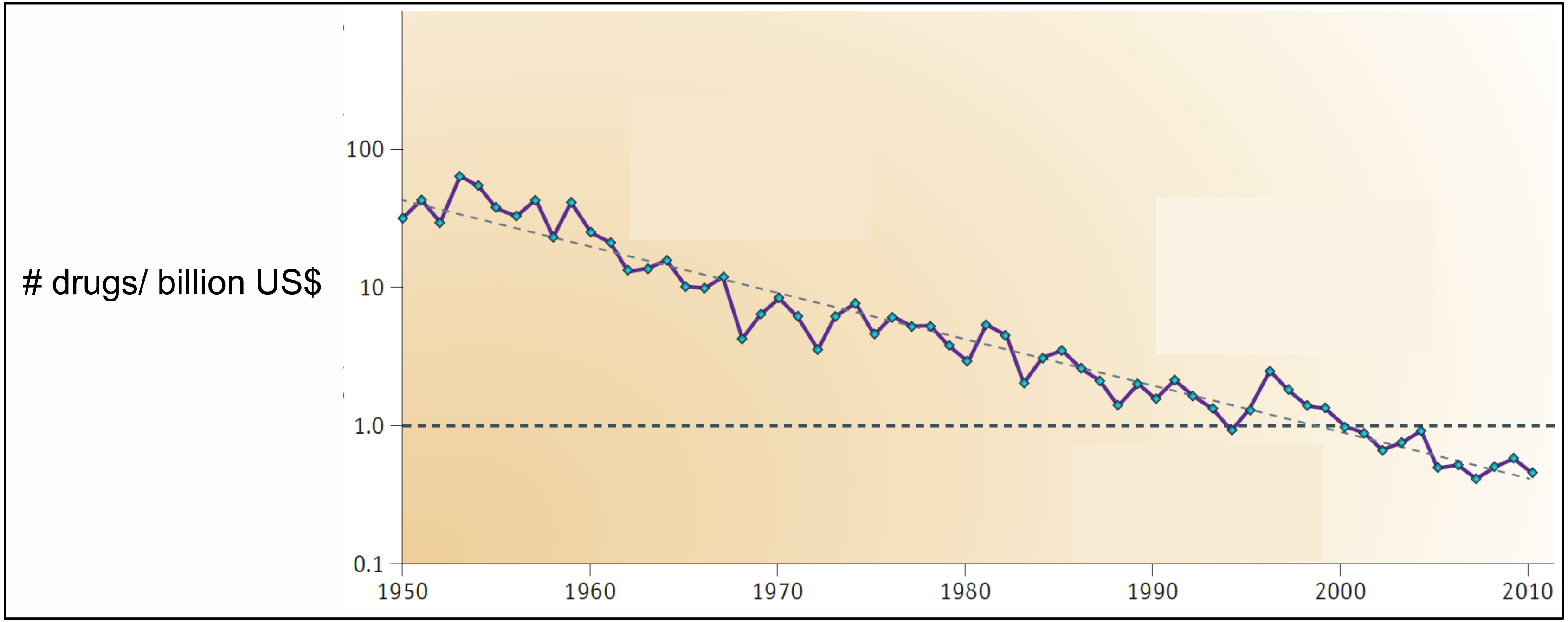
Eroom's Law

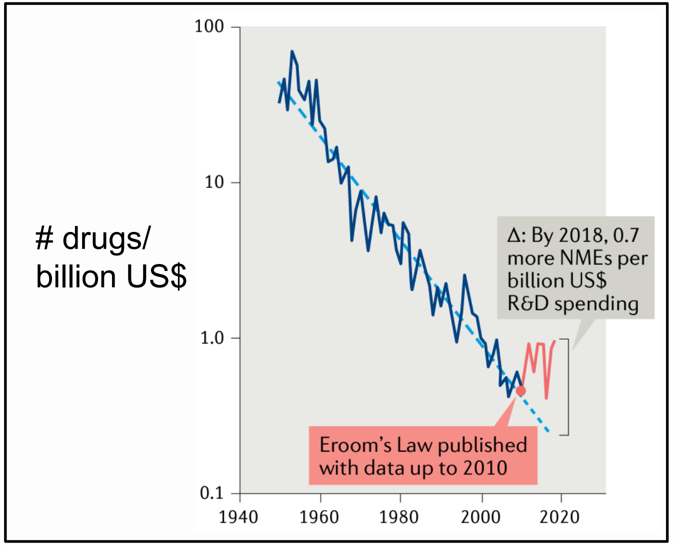


Scannell et al., (2012), *Nature Reviews Drug Discovery*

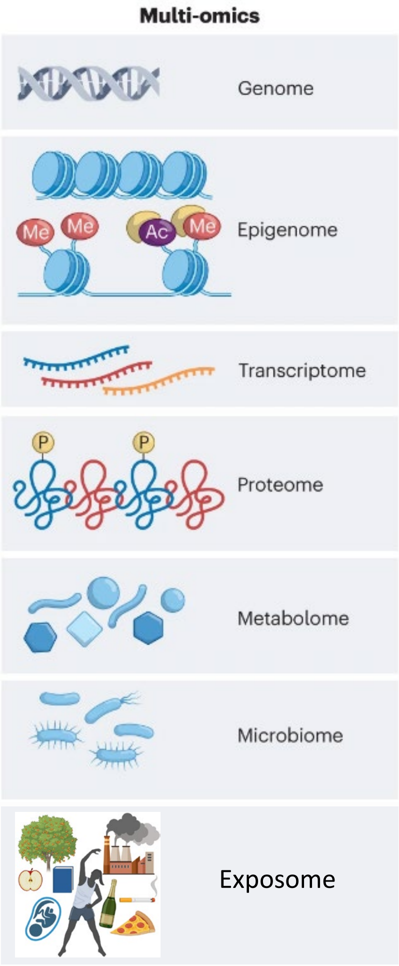
We've seen an exponential decline in pharmaceutical R&D efficiency.

Rationale

Breaking Eroom's Law



Ringel et al., (2020), *Nature Reviews Drug Discovery*



Health Data Analytics and Machine Learning will teach you to extract features from, predict, and infer causes of human biological states.

Eroom's Law can be broken through a better understanding of human biology.

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Learning outcomes

- Biomedical science
  - Molecules of life I
    - Atoms and periodicity
    - Carbon
    - Water
    - Carbohydrates
    - Lipids
    - Proteins
  - Molecules of life II
    - Nucleic acids
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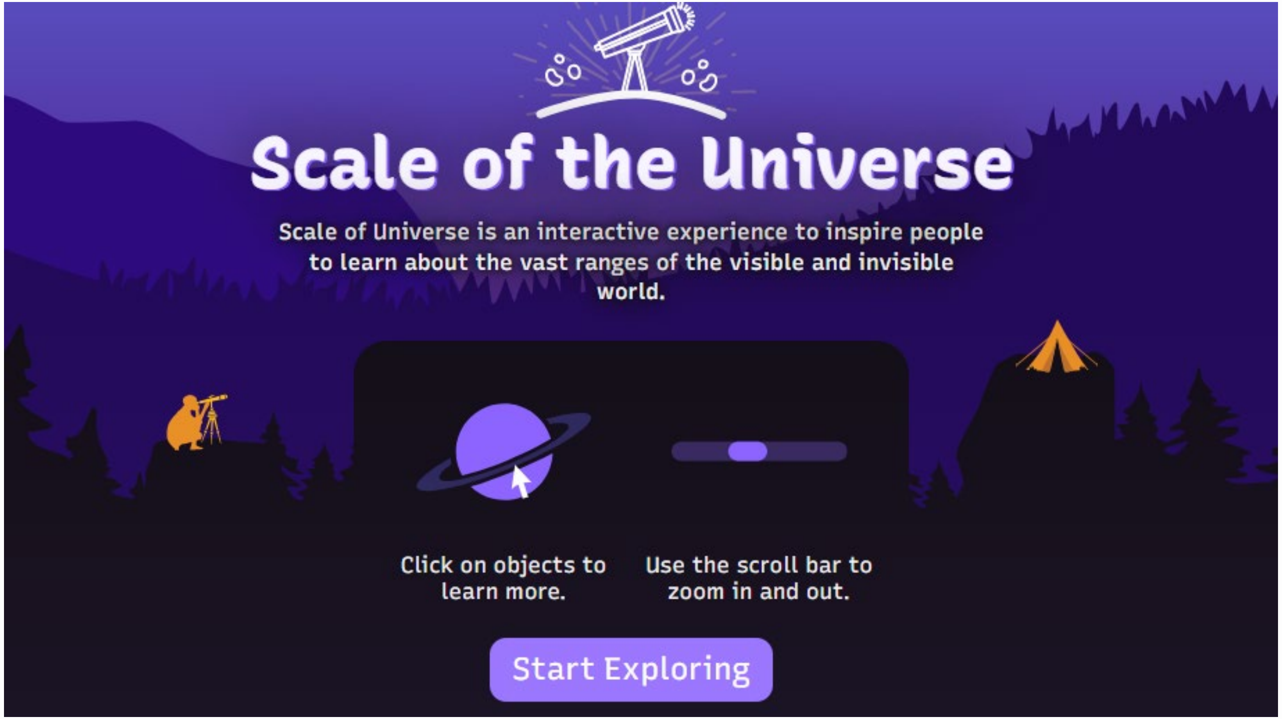
    - OMICs Technologies

Interactive scale of the universe

https://scaleofuniverse.com/en-gb



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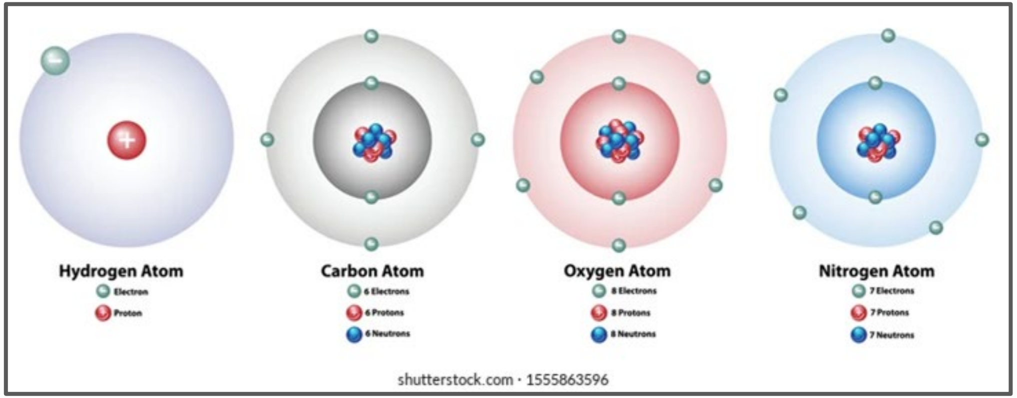
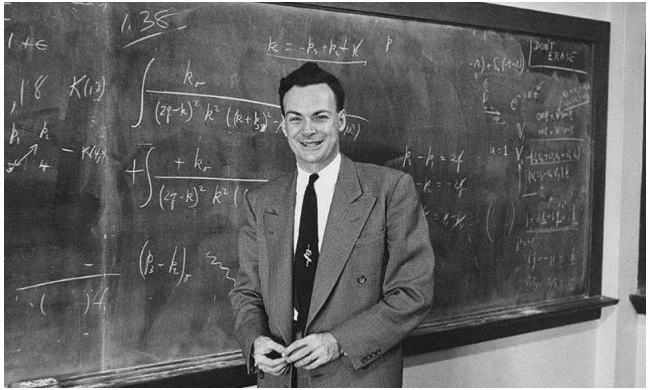
Atoms

- An atom is the smallest unit of matter that forms a chemical element.
- A chemical element is a pure substance made of only one type of atom.





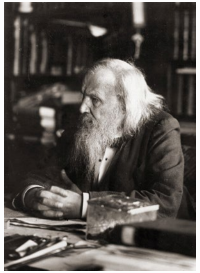
Richard Feynman (1918 - 1988):

Asked if only one sentence could be passed on, would pass on:
“all things are made of atoms”

All things are made of atoms.

Periodic table of chemical elements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H hydrogen 1																	He helium 2
2	Li lithium 3	Be beryllium 4											B boron 5	C carbon 6	N nitrogen 7	O oxygen 8	F fluorine 9	Ne neon 10
3	Na sodium 11	Mg magnesium 12											Al aluminium 13	Si silicon 14	P phosphorus 15	S sulfur 16	Cl chlorine 17	Ar argon 18
4	K potassium 19	Ca calcium 20	Sc scandium 21	Ti titanium 22	V vanadium 23	Cr chromium 24	Mn manganese 25	Fe iron 26	Co cobalt 27	Ni nickel 28	Cu copper 29	Zn zinc 30	Ga gallium 31	Ge germanium 32	As arsenic 33	Se selenium 34	Br bromine 35	Kr krypton 36
5	Rb rubidium 37	Sr strontium 38	Y yttrium 39	Zr zirconium 40	Nb niobium 41	Mo molybdenum 42	Tc technetium 43	Ru ruthenium 44	Rh rhodium 45	Pd palladium 46	Ag silver 47	Cd 48	In indium 49	Sn tin 50	Sb antimony 51	Te tellurium 52	I iodine 53	Xe xenon 54
6	Cs caesium 55	Ba barium 56	57–71 see below	Hf hafnium 72	Ta tantalum 73	W tungsten 74	Re rhenium 75	Os osmium 76	Ir iridium 77	Pt platinum 78	Au gold 79	Hg mercury 80	Tl thallium 81	Pb lead 82	Bi bismuth 83	Po polonium 84	At astatine 85	Rn radon 86
7	Fr francium 87	Ra radium 88	89–103 see below	Rf rutherfordium 104	Db dubnium 105	Sg seaborgium 106	Bh bohrium 107	Hs hassium 108	Mt meitnerium 109	Ds darmstadtium 110	Rg roentgenium 111	Cp copernicium 112	Uut ununtrium 113	Fl flerovium 114	Uup Ununpentium 115	Lv Livermorium 116	Uus Ununseptium 117	Uuo Ununoctium 118
				La lanthanum 57	Ce cerium 58	Pr praseodymium 59	Nd neodymium 60	Pm promethium 61	Sm samarium 62	Eu europium 63	Gd gadolinium 64	Tb terbium 65	Dy dysprosium 66	Ho holmium 67	Er erbium 68	Tm thulium 69	Yb ytterbium 70	Lu Lutetium 71
				Ac actinium 89	Th thorium 90	Pa protactinium 91	U uranium 92	Np neptunium 93	Pu plutonium 94	Am americium 95	Cm curium 96	Bk berkellium 97	Cf californium 98	Es einsteinium 99	Fm fermium 100	Md mendelevium 101	No nobelium 102	Lr Lawrencium 103

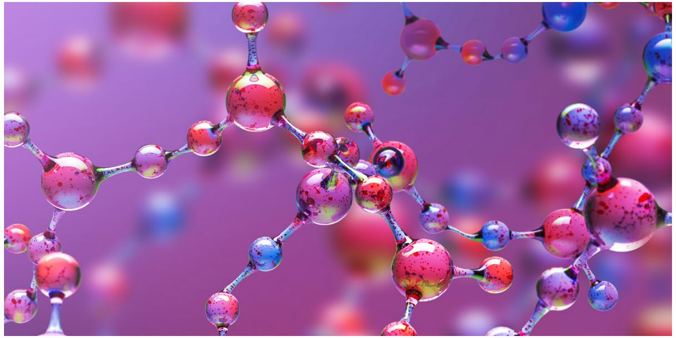


Dmitri Mendeleev
(1834 - 1907)

The periodic table organises chemical elements (substances that cannot be decomposed) into groups (columns) of similar properties.

Molecules

- The roughly 100 elements combine to form hundreds of millions of molecules.
- They combine through **chemical bonding**.
- Atoms linked by bonds have very different properties from their parent atoms.

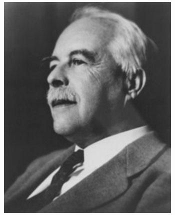


Life is based on molecules, which are composed of combinations of elements.

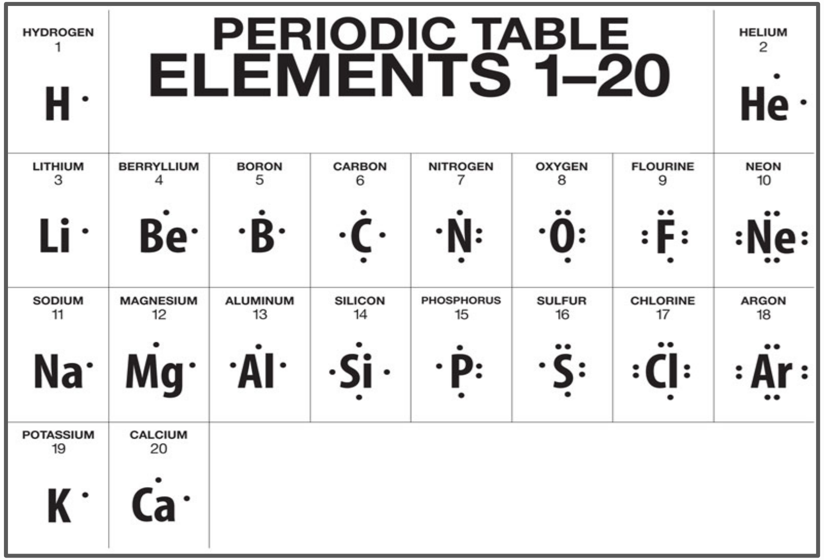
Atoms and periodicity

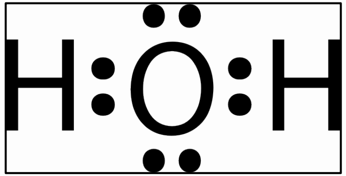
Lewis dot structures

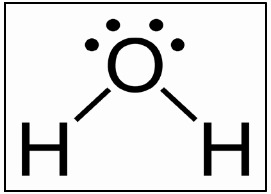
- Lewis dot structures display the element and the number of electrons in the atom's outermost shell.

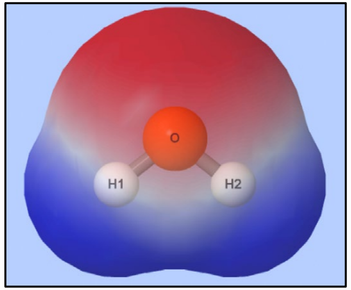


Gilbert Lewis
(1875 - 1946)



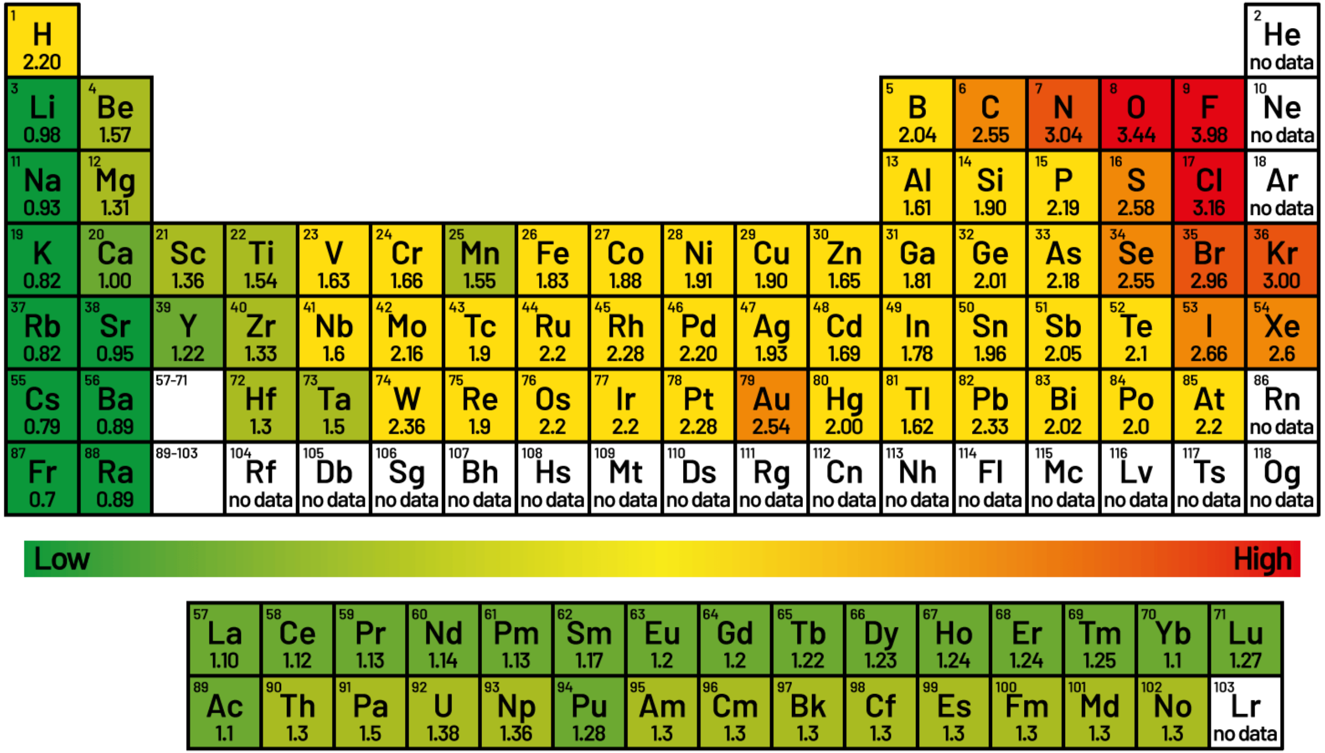


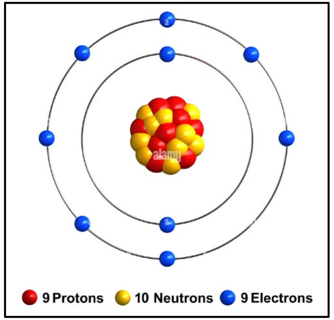




Lewis dot structures help us visualise the bonding between atoms of a molecule.

Electronegativity





An element's electronegativity is a measure of the ability of its atoms to attract electrons in a chemical bond.

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Duplet and octet rules

- Duplet rule: Hydrogen and Helium each prefer to have 2 electrons in their outer shell.
- Octet rule: Elements in groups 1 - 2, and groups 13 - 18 prefer 8 electrons in their outer shell.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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La lanthanum 57	Ce cerium 58	Pr praseodymium 59	Nd neodymium 60	Pm promethium 61	Sm samarium 62	Eu europium 63	Gd gadolinium 64	Tb terbium 65	Dy dysprosium 66	Ho holmium 67	Er erbium 68	Tm thulium 69	Yb ytterbium 70	Lu Lutetium 71
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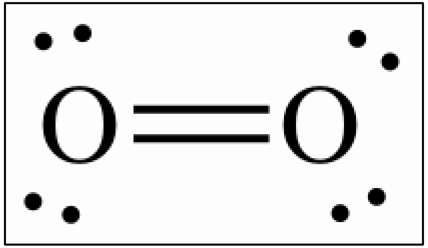
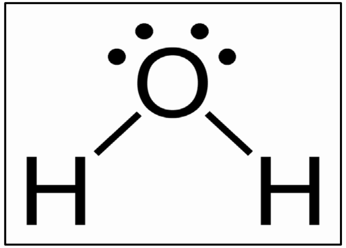
The duplet and octet rules are rules of thumb that main-group elements bond in a way that each atom has 2 (H, and He) or 8 electrons.

Molecular bonds

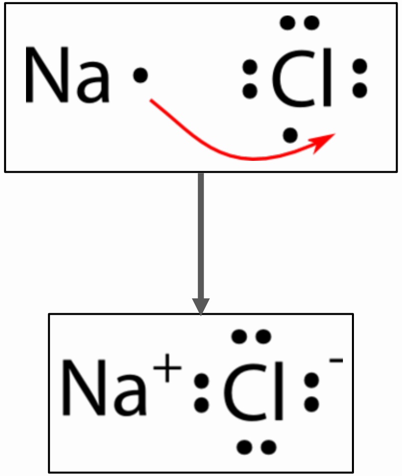
1. Covalent bond





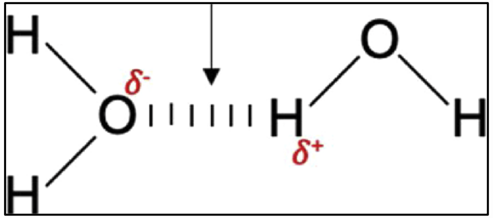
Electrons are shared between atoms in a stable way

2. Ionic bond



Electrons are transferred and the ions are attracted to each other

3. Hydrogen bond

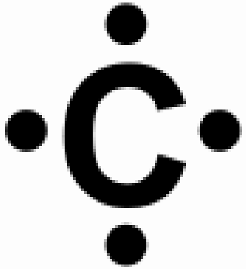


Attraction between molecules or atoms when hydrogen is bonded to a more electronegative donor (e.g. O, N, F)

The three main types of molecular bonding that are relevant to biology are covalent bonds, ionic bonds, and hydrogen bonds.

Carbon-based life

- 0.025% Earth's crust – yet forms more compounds than all the other elements combined.
- 45-50% of all dry biomass.
- Subject of organic chemistry: > 10 million known organic molecules.



Carbon-based molecules that sustain life

Molecule	Subcomponents (building blocks)
Carbohydrates	Monosaccharides
Lipids	Glycerol, fatty acids, phosphate groups
Proteins (polypeptides)	Amino acids
Nucleic acids	Nucleotides

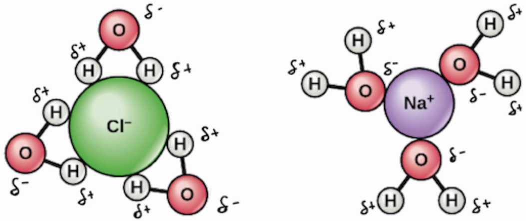
Carbon enables life due to its unique ability to form stable, diverse, and complex bonds.

Water properites

- High cohesion allows for high surface tension

- Adhesive

- Good solvent



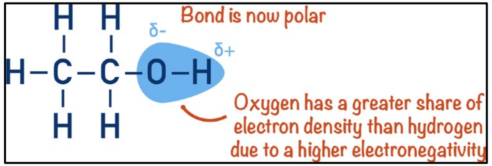
Water is the medium of life because it has many useful properties.

Hydrophiles and hydrophobes

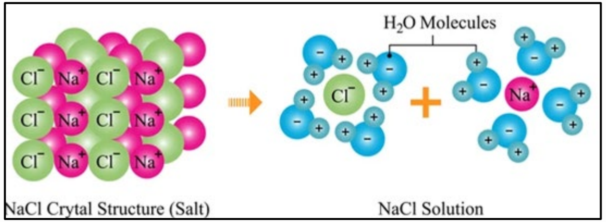
- Hydrophilic substances:

  alcohol, sugar, salt

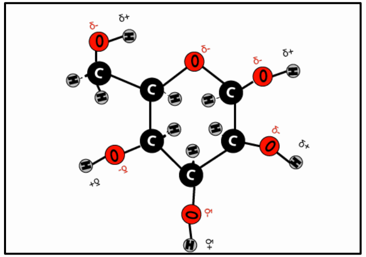
Ethanol



Salt (NaCl)

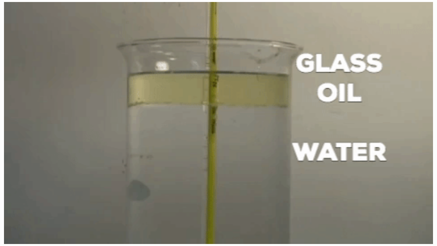


Glucose

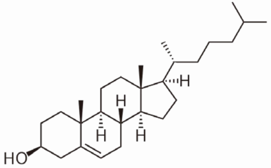


- Hydrophobic substances:

  lipids, alkanes (hydrocarbons)



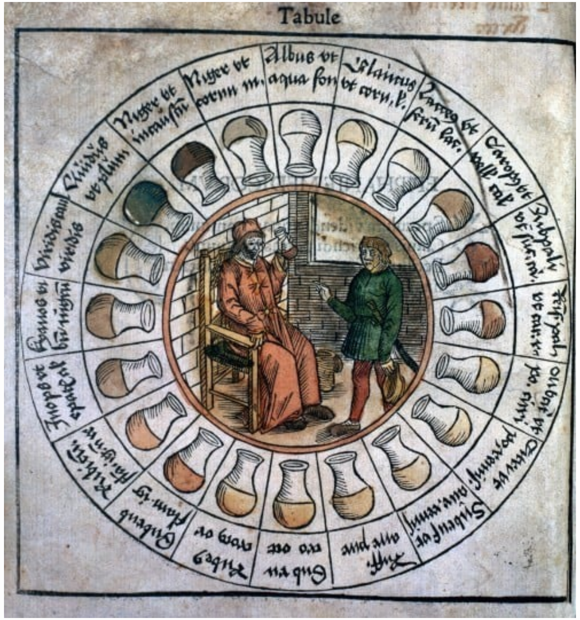
Cholesterol



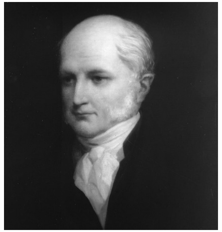
Molecules either love or hate water.

Macromolecules

- We have records dating back to 4000 BCE of people studying urine to determine a person's health.



- William Prout studied urine and proposed the classification of food into carbohydrates, lipids, and proteins.



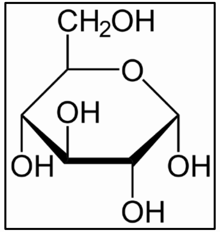
William Prout (1785 - 1850)

All organisms need to either synthesise or ingest carbohydrates, lipids, and proteins to live.

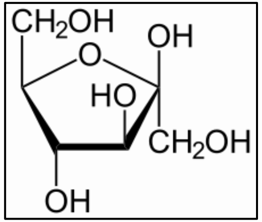
Carbohydrates

- Source of energy.
- Made up of sugars.
- Simplest sugars are monosaccharides.

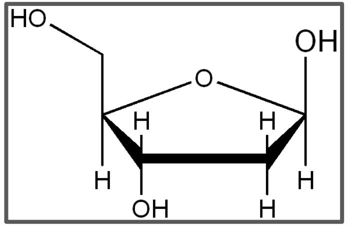
Glucose ($C_6H_{12}O_6$)



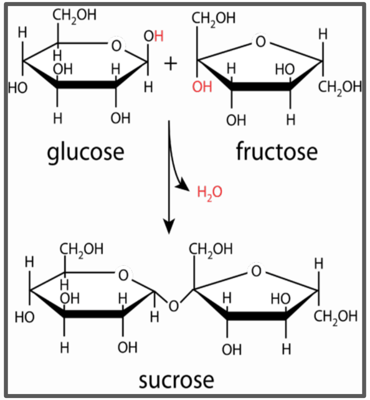
Fructose ($C_6H_{12}O_6$)

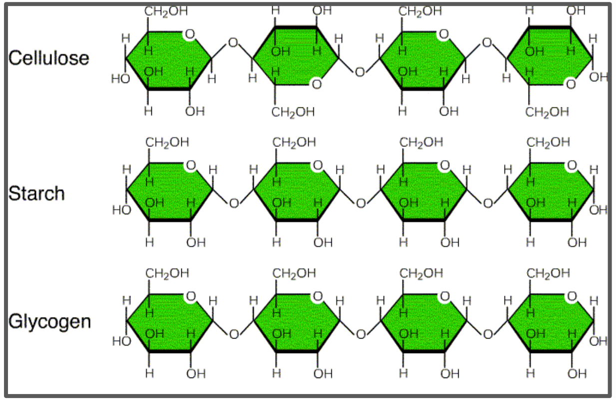


Deoxyribose ($C_5H_{10}O_4$)



- Monosaccharides can bond to form disaccharides and polysaccharides.





Plants store energy from the sun in the form of carbohydrates, and animals eat these.

Lipids store energy

Main categories:

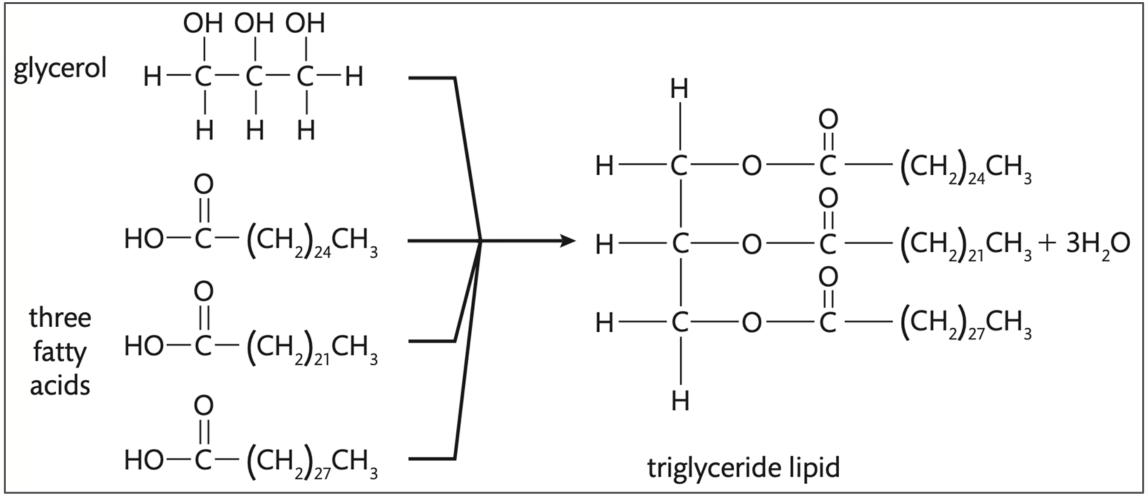
- Triglycerides
- Fatty acids
- Phospholipids
- Steroids

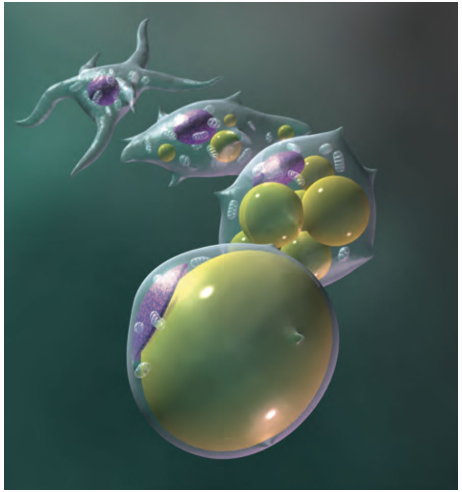
Properties:

- Insoluble in water.
- Long-term energy storage.

Triglycerides

- Stored in adipocytes (fat cells)
- Formed from glycerol and three fatty acids





Triglycerides are stored in adipocytes and are broken down into constituents when needed.

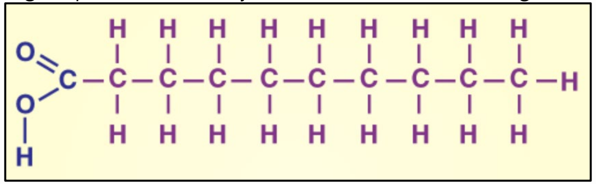
Lipids

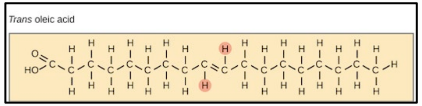
Fatty acids

For cardiovascular health, best to worst.

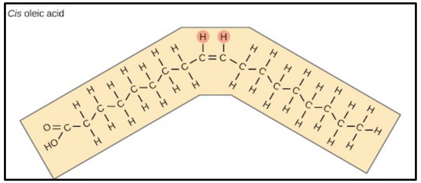
Carboxyl group | Hydrocarbon chain (usually 11 - 23 carbons) | Methyl group (omega end)

- Saturated

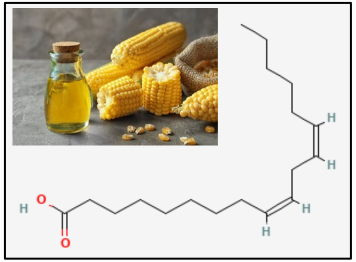


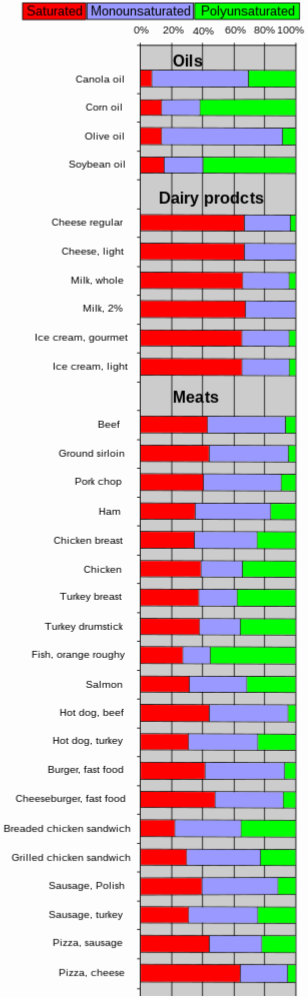


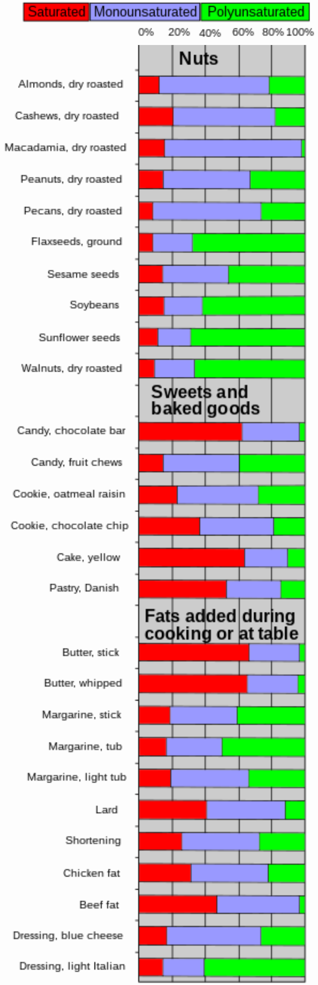
- Monounsaturated



- Polyunsaturated

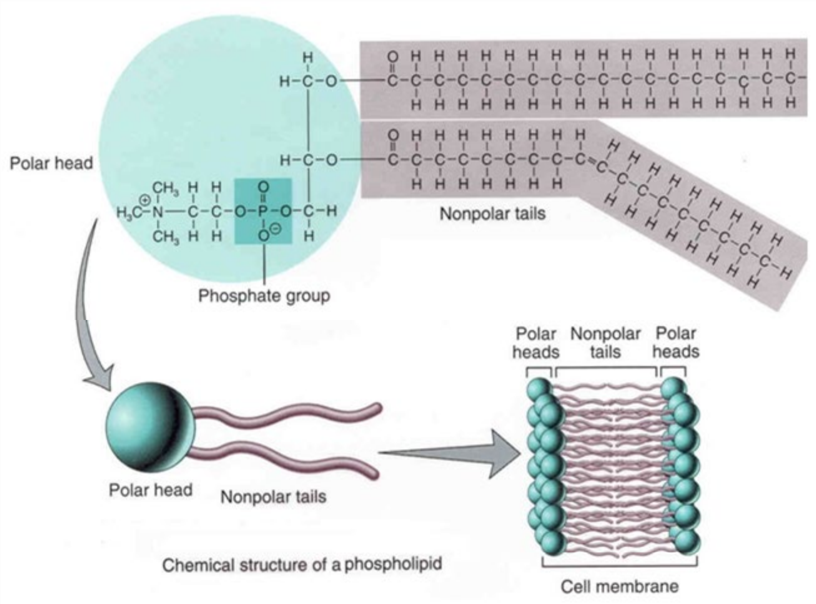


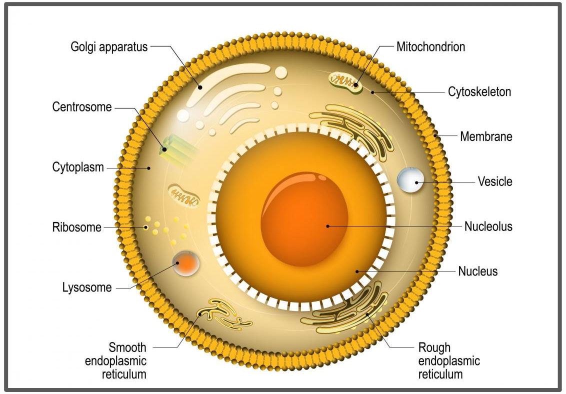


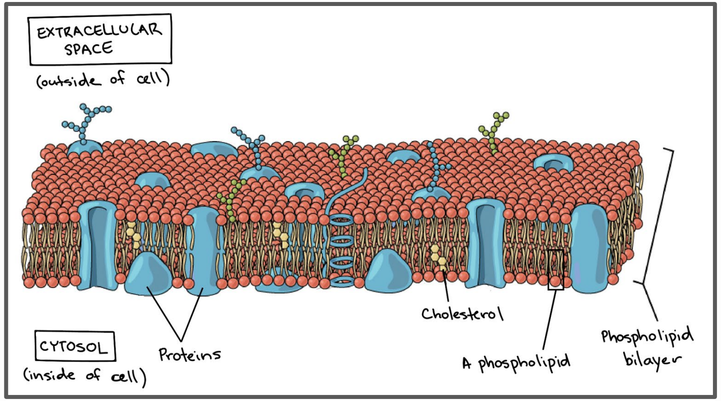


Fatty acids can be used as a source of energy in cells.

Phospholipids



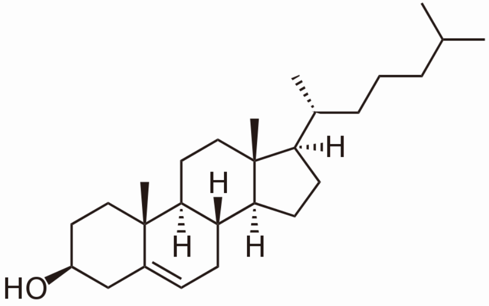




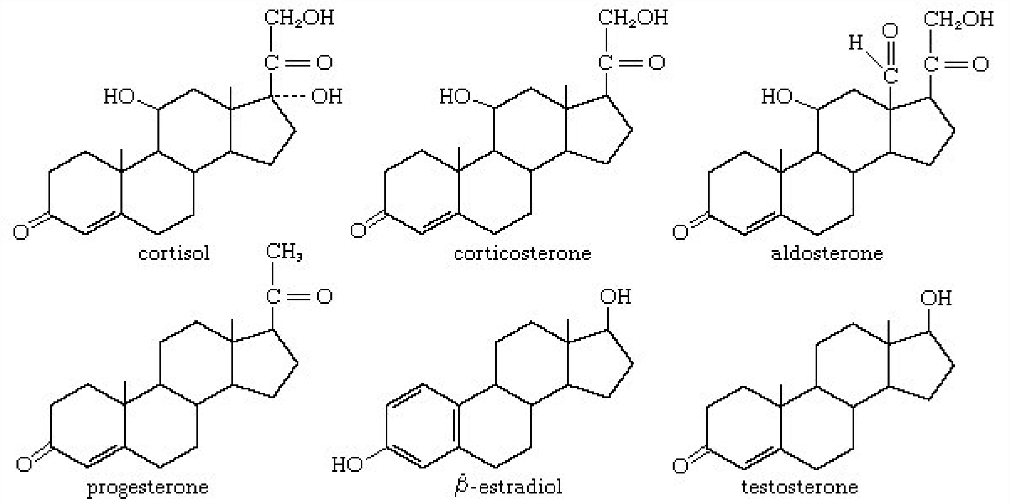
Phospholipids form the basis of our 37 trillion (10^{12}) cell membranes.

Steroids

- 17 carbon atoms arranged in four rings.



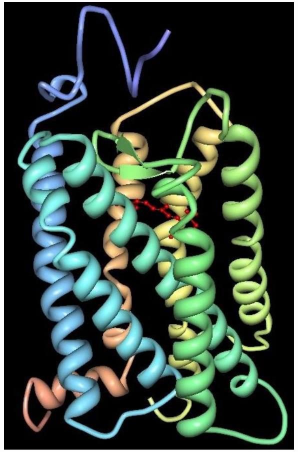
Cholesterol



Steroids play important roles in membrane fluidity and cell signalling.

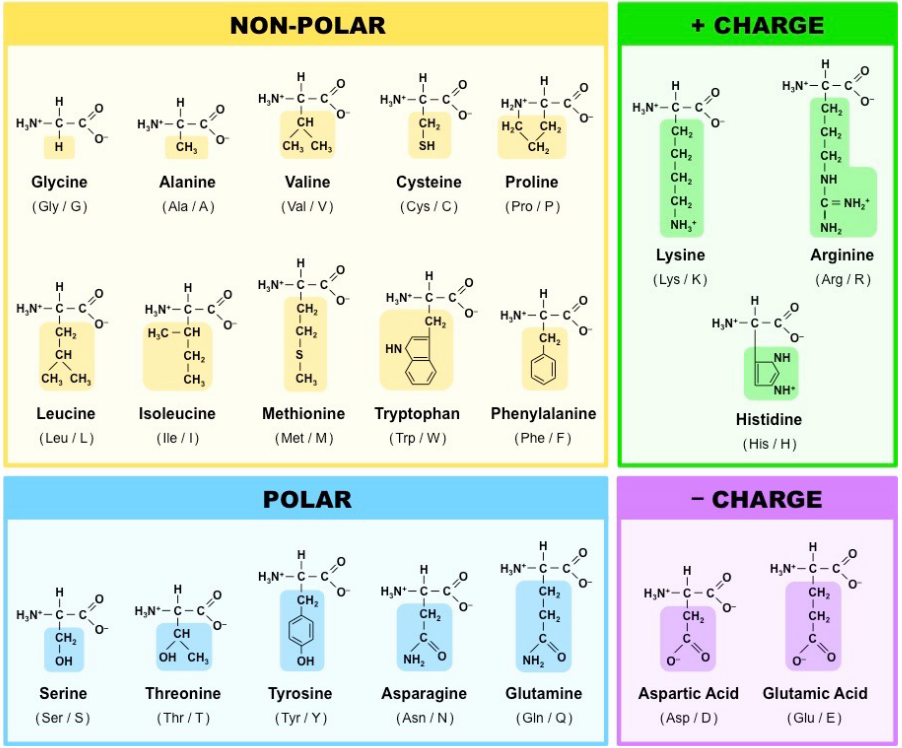
Proteins

- **Enzymes** catalyse reactions; e.g. pepsin in gastric juices breaks down food particles.
- **Antibodies** fight infections; e.g. immunoglobulin G binds to pathogens such as viruses and bacteria.
- **Protein hormones** elicit biological actions in organs or tissues; e.g. insulin regulates the level of sugar in the blood.
- **Structural proteins** provide structure; e.g. collagen is the structural protein in bones, tendons, ligaments, and skin.
- **Sensory proteins** allow cells to interact with the environment and respond to signals; e.g. rhodopsin converts light to an electrical signal in eyes.

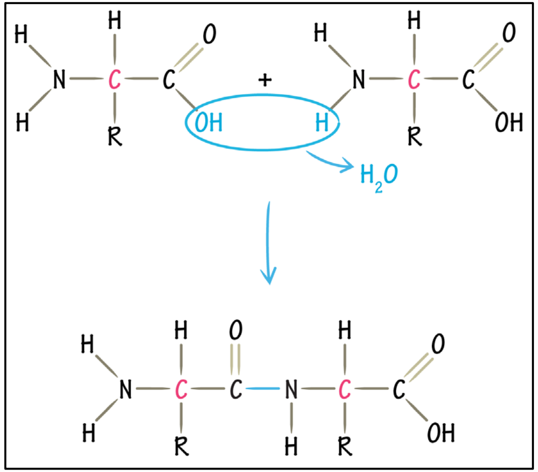


Proteins are the workhorses of the cell.

Amino acids

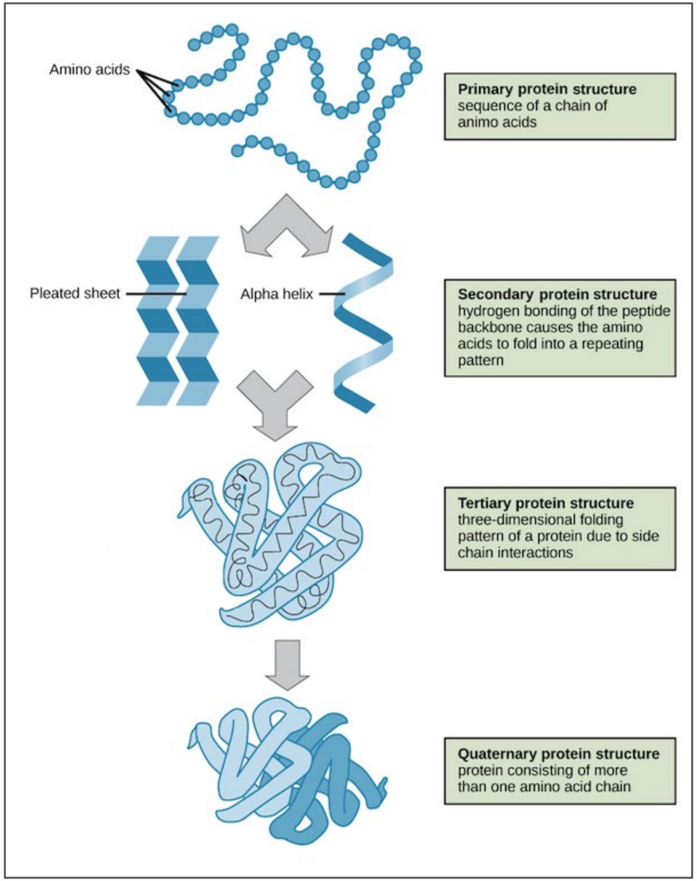


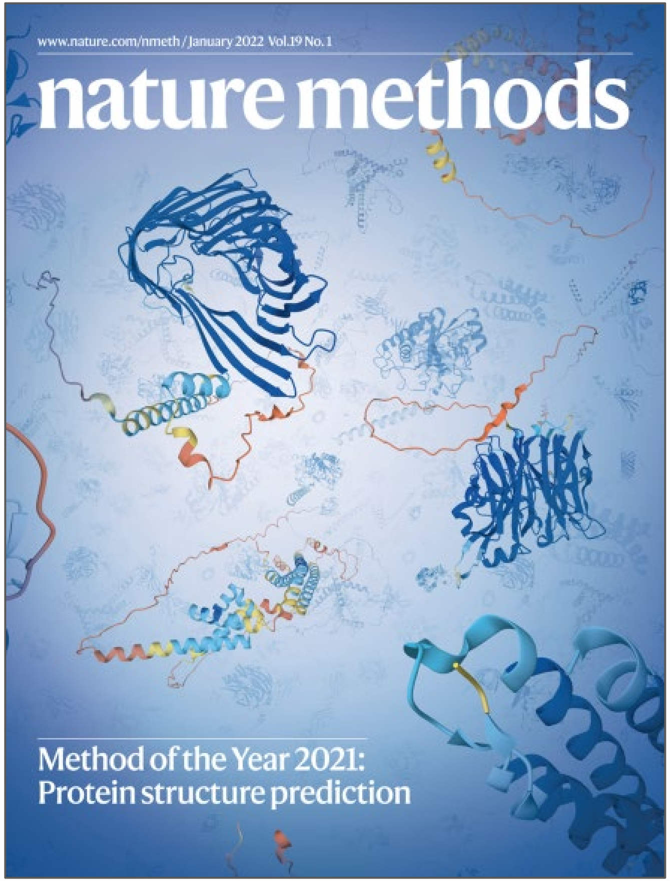
- 20 amino acids are the building blocks of all proteins, of which there are 1-3 billion per cell.
- Amino acids bond to form chains.



Humans have 20 amino acids, which form 20,000 distinct proteins made from an average of 400 (range: 50-1000) amino acids.

Levels of protein structure





Protein structure is important for protein function, and difficult to predict.

Learning outcomes

- **Biomedical science**
  - Molecules of life I
    - Atoms and periodicity
    - Carbon
    - Water
    - Carbohydrates
    - Lipids
    - Proteins
  - Molecules of life II
    - Nucleic acids
    - DNA and RNA
    - Heredity and genetics
  - Cells
    - Cell theory
    - Ultrastructure
    - Cell cycle
    - Mitosis
    - Meiosis
  - The central dogma I
    - The central dogma
    - Transcription
    - Translation
    - Mutations
  - The central dogma II
    - Gene regulation
    - OMICs Technologies

Thank you for listening!

Introduction to Biomedical Science - 2nd Session: Molecules of Life II

Sonja N. Tang, MSc

(sonja.tang19@imperial.ac.uk)

Learning outcomes

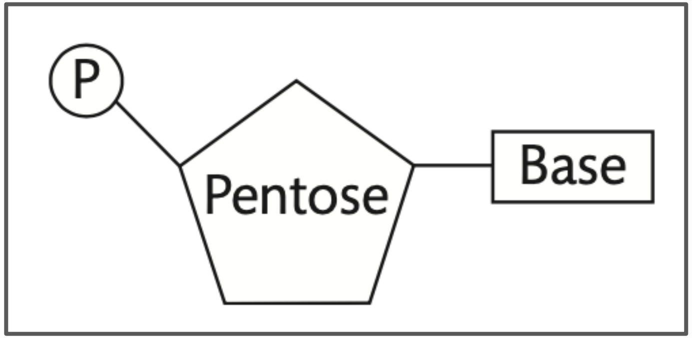
Biomedical science

- **Molecules of life I**
  - Atoms and periodicity
  - Carbon
  - Water
  - Carbohydrates
  - Lipids
  - Proteins
- **Molecules of life II**
  - Nucleic acids
  - DNA and RNA
  - Heredity and genetics
- **Cells**
  - Cell theory
  - Ultrastructure
  - Cell cycle
  - Mitosis
  - Meiosis
- **The central dogma I**
  - The central dogma
  - Transcription
  - Translation
  - Mutations
- **The central dogma II**
  - Gene regulation
  - OMICs Technologies

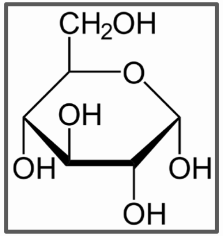
Nucleic acids

- Nucleic acids are the primary information-carrying molecules in cells and make up the genetic material required for life.
- The main classes are:
  - Deoxyribonucleic acid (DNA) (basis of the genome)
  - Ribonucleic acid (RNA) (basis of the transcriptome).
- Composed of buildings blocks called nucleotides.

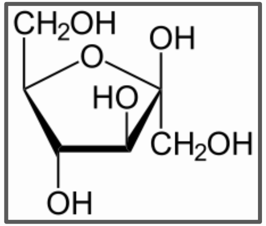
Simplified nucleotide



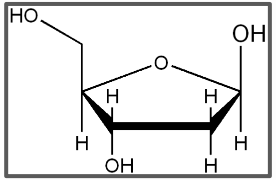
Glucose ($C_6H_{12}O_6$)



Fructose ($C_6H_{12}O_6$)

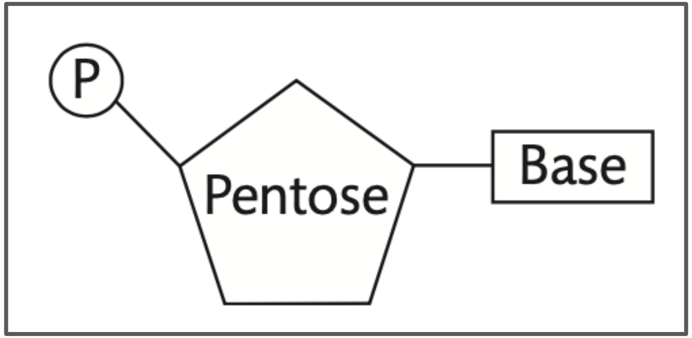


Deoxyribose ($C_5H_{10}O_4$)

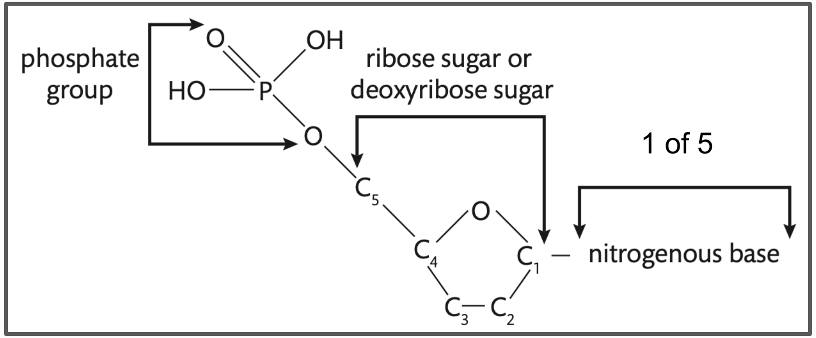


Nucleic acids store complete information for all the proteins needed to make a person.

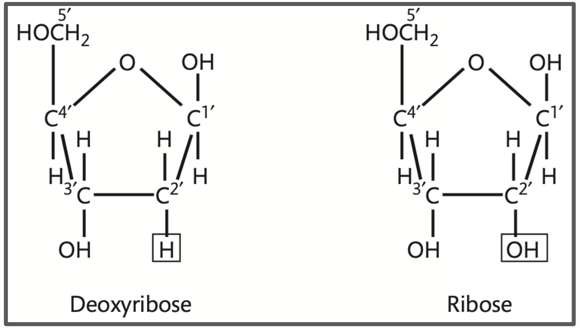
Nucleotides



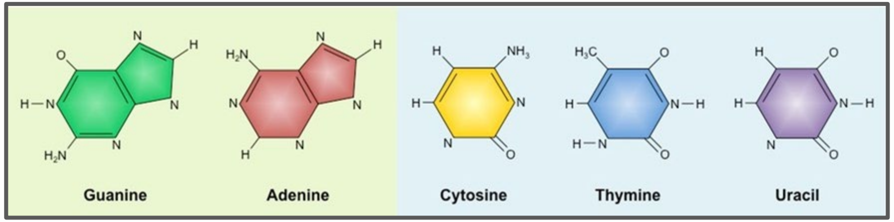
Chemical composition of a nucleotide



Pentose



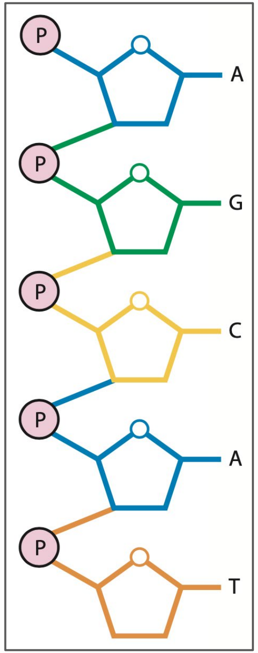
Nitrogenous bases



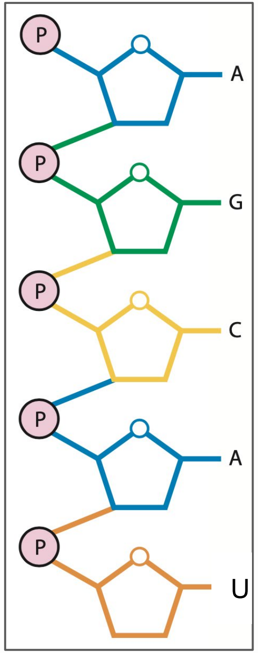
Nucleotides can come in 5 flavours. DNA: C-G, A-T. RNA: C-G, A-U.

Nucleotide chains

Half a strand of Deoxyribonucleic acid (DNA)

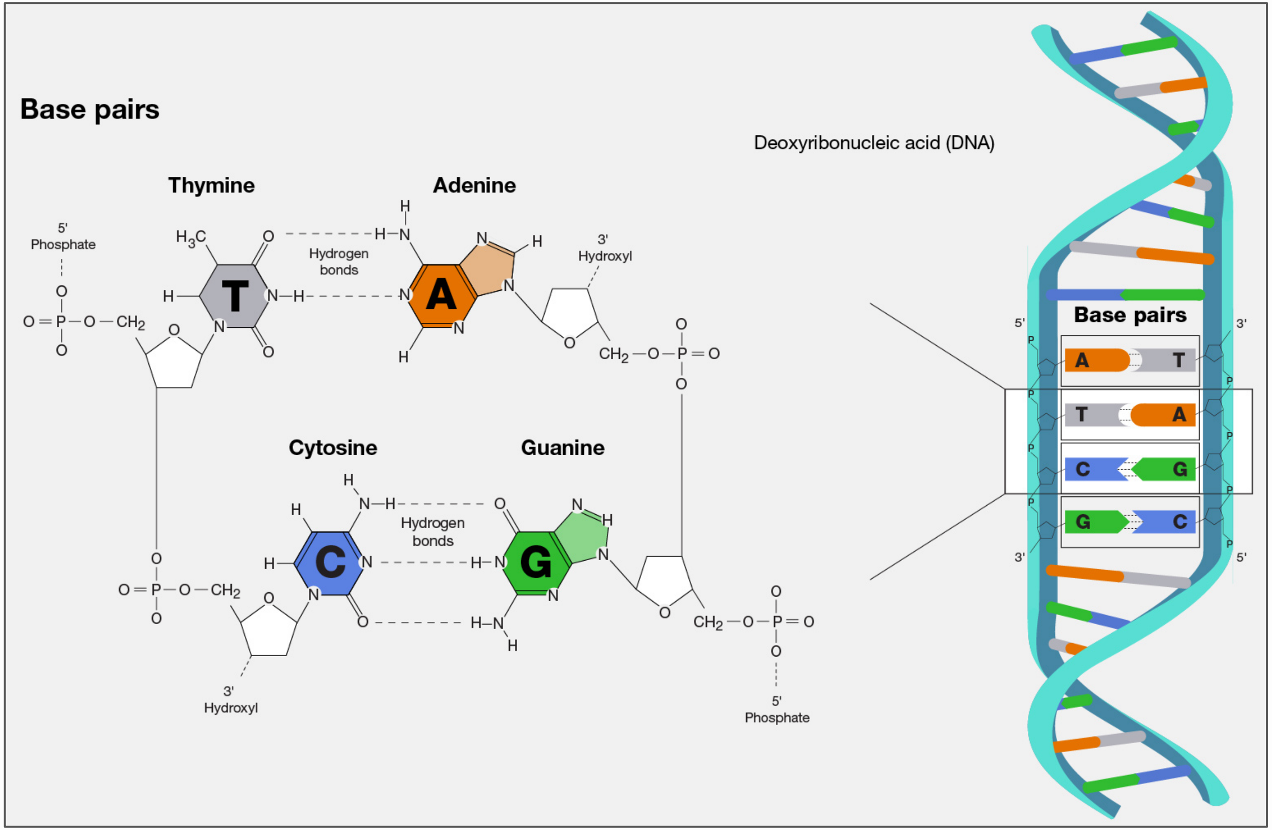


Ribonucleic acid (RNA)



Nucleotides bond together to form long chains of DNA and RNA.

Complementary base pairing



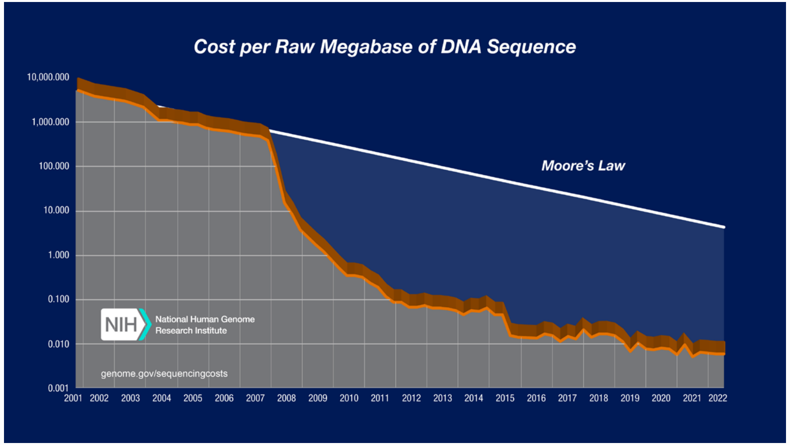
Nucleotide bases form hydrogen bonds with complementary bases (C-G and T/U-A).

Deoxyribonucleic acid (DNA)

- Passed down from our species' shared ancestors in Africa, and looking further back, from our single-celled ancestors 4 billion years ago.

- Consists of 3.1 billion base pairs.

- First sequenced between 1990 and 2003 by the Human Genome Project for $3 billion.



Parlato said, calling civil disobedience the antithesis of the violent militia movement. Such non-violence can serve as an antidote to government oppression, he added.

"If a law is unjust or you're given an order without moral or legal authority,

The Lapps and Parlato will be joined by Samuel Radford III, a critic of public education who was arrested and pleaded guilty to reduced charges following a 1993 disturbance at the City Campus of Erie Community College.

WANTED

20 Volunteers

to participate in the

Human Genome Project

a very large international scientific research effort.

The goal is to decode the human hereditary information (*human blueprint*) that determines all individual traits inherited from parents. The outcome of the project will have tremendous impact on future progress of medical science and lead to improved diagnosis and treatment of hereditary diseases.

Volunteers will receive information about the project from the Clinical Genetics Service at Roswell Park, and sign a consent form before participating.

No personal information will be maintained or transferred.

Volunteers will provide a one-time donation of a small blood specimen. A small monetary reimbursement will be provided to the participants for their time and effort.

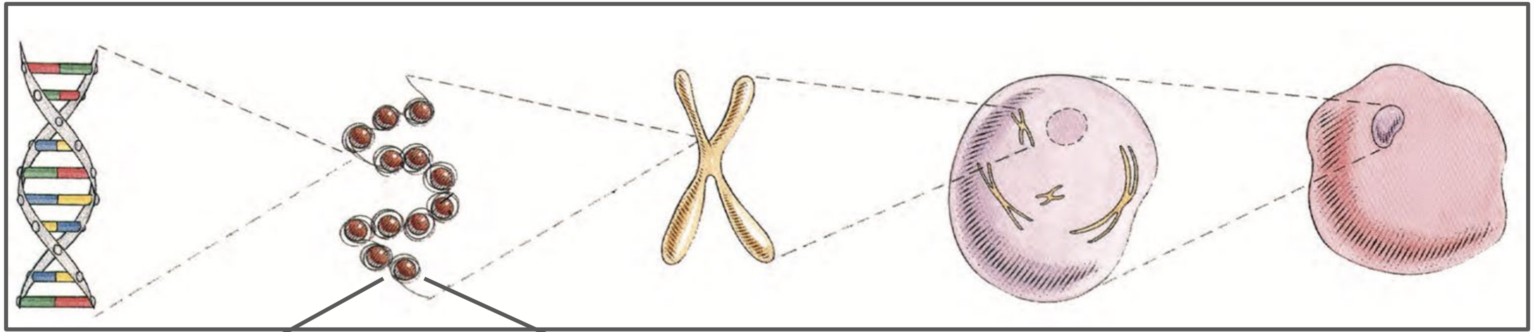
Individuals must be at least 18 years of age.
Persons who have undergone chemotherapy are not eligible.

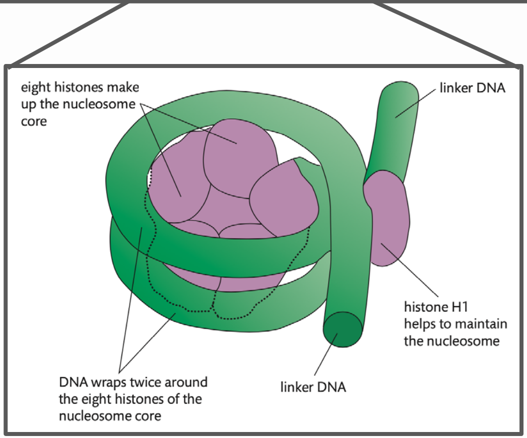
ROSWELL PARK CANCER INSTITUTE

For more information please contact the
Clinical Genetics Service
845-5720 (9:00 am - 3:00 pm)
March 24 - 26, 1997

DNA is the world's best data storage.

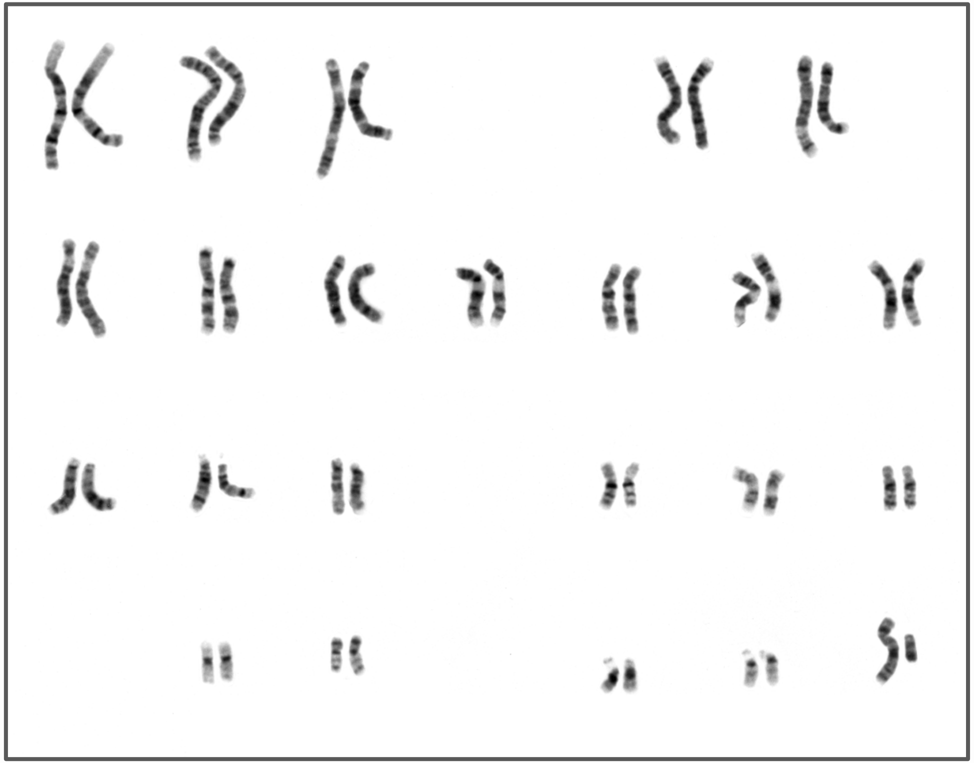
DNA packaging





DNA is packaged to fit into each of our 40 trillion cells. If we stretched out all the DNA from all our cells end to end, it would span the length of the solar system.

Chromosomes



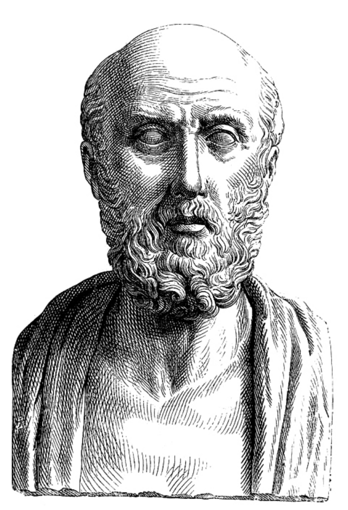
- **Somatic cells** are cells of the body with 2 * 23 chromosomes (diploid). Soma means body in Greek.
- **Gametes** are reproductive cells with1 * 23 chromosomes (haploid).

- Chromosomes 1-22 are autosomes. Chromosome 23 is a sex chromosome.

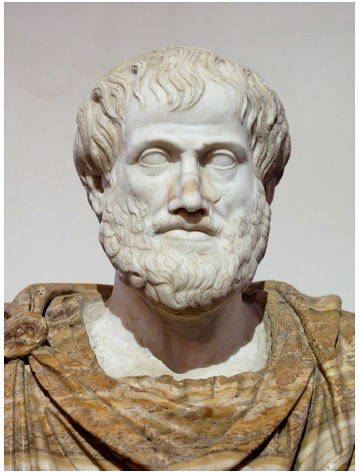
DNA is packaged into 23 distinct chromosomes.

Early hypotheses surrounding heredity

6000-year-old pedigree (a record of the ancestry or purity of the breed).



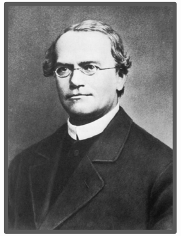
Hippocrates
(c. 460 - 375 BCE):
Proposed "bricks and mortar" hypothesis



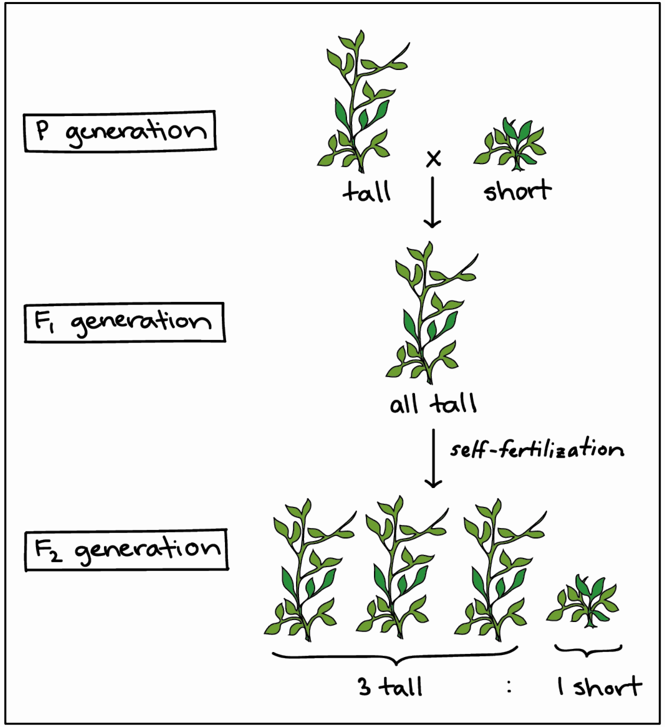
Aristotle
(384 - 322 BCE):
Believed blood enabled heredity

Heredity has been a concern of humans for many millennia.

Mendel's studies of heredity



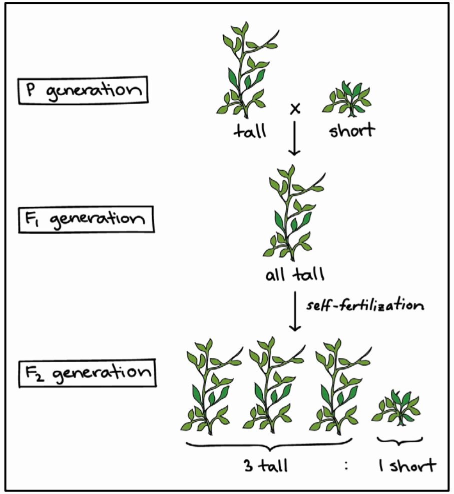
Gregor Mendel
(1822 - 1884):



- Characteristics such as flower colour and plant height, were controlled by pairs of heritable factors that came in different versions.
- One version of a factor (dominant) could mask the presence of another version (recessive).
- The two paired factors separated during gamete production, such that each gamete (sperm or egg) randomly received just one factor.

Mendel deduced that there are discrete hereditary units (genes) that come in different versions (alleles).

Monohybrid cross



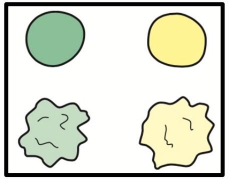
Punnett grid
of F_2 (second filial generation)

	A	a
A	AA	Aa
a	Aa	aa

- Monohybrid cross - a cross between two heterozygotes.
- Heterozygote - an individual having two different alleles of a particular gene or genes, and so giving rise to varying offspring.
- Allele - each of two or more alternative forms of a gene that arise by mutation and are found at the same place on a chromosome.
- A – dominant
- a – recessive
- AA – homozygous dominant
- aa – homozygous recessive
- Aa - heterozygous

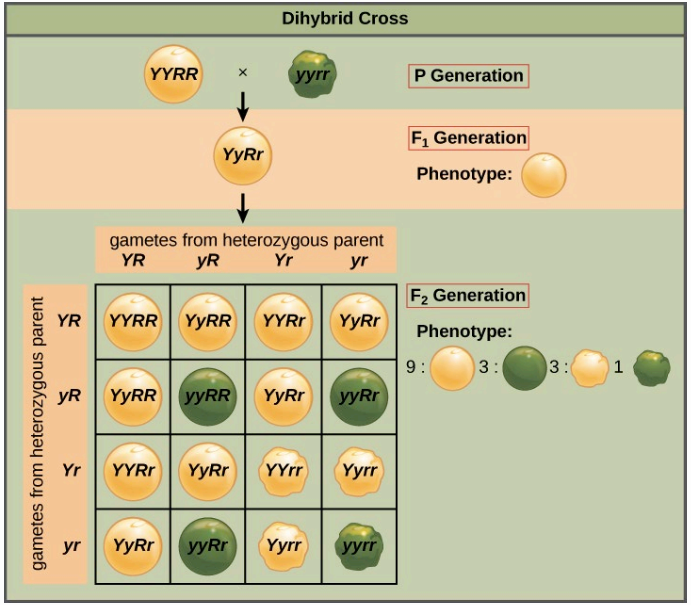
Law of segregation: each gamete randomly receives one allele of the gene.

Dihybrid cross



Dihybrid - a heterozygous hybrid for alleles of two different genes.

- The alleles for shape: **round** is dominant, while **wrinkled** is recessive.
- The alleles for colour: **yellow** is dominant, while **green** is recessive.



Law of independent assortment: the factors controlling different characteristics (e.g. shape and colour) are inherited independently of one another.

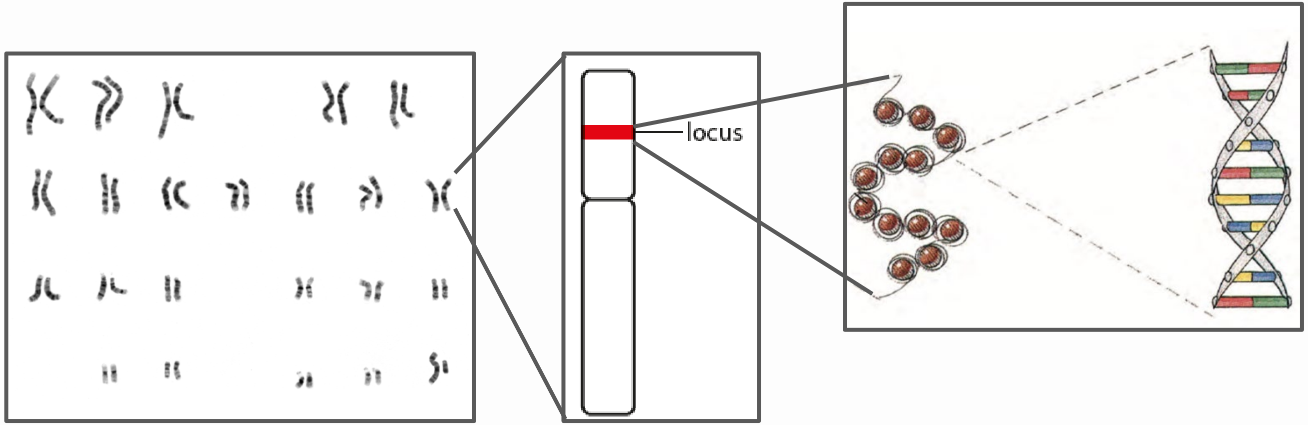
Genes

- A gene is a **heritable** factor that consists of a length of DNA and influences **one** or **many characteristics**.
- **Heritable** = passed on from parent to offspring.
- **Characteristic** = genetic traits such as blood type, eye colour, etc.

- **One** gene influences **one characteristic** = Mendelian gene
- **One** gene influences **many characteristics** = Pleiotropic gene.

- **Many** genes influence **one characteristic** = Polygenic trait.

Genes



- A gene occupies a specific **position** (**locus**) on a chromosome.
- ~20,000 protein-coding genes in humans.
- 6.2 billion base pairs in the genome: 3.1 billion each from the mother and the father.
- 6.5 genes per million base pairs, but distribution is highly uneven.

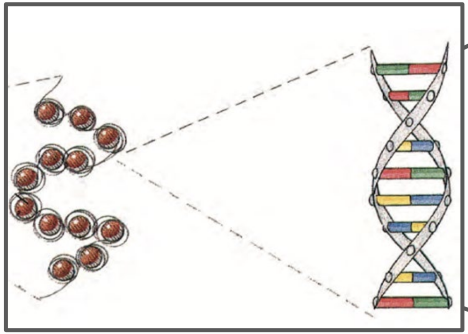
Only 1% of the genome codes for genes.

Genome sizes to number of genes

Common Names	Estimated Total Size of Genome (bp)*	Estimated Number of Protein-Encoding Genes*
Unicellular budding yeast	12 million	6,000
Unicellular malaria parasite	23 million	5,000
Nematode	95.5 million	18,000
Fruit fly	170 million	14,000
Mustard; thale cress	125 million	25,000
Rice	470 million	51,000
Chicken	1 billion	23,000
Domestic dog	2.4 billion	19,000
Laboratory mouse	2.5 billion	30,000
Human	**3.1 billion**	**20,000**
Salamander	3.2 billion	23,000

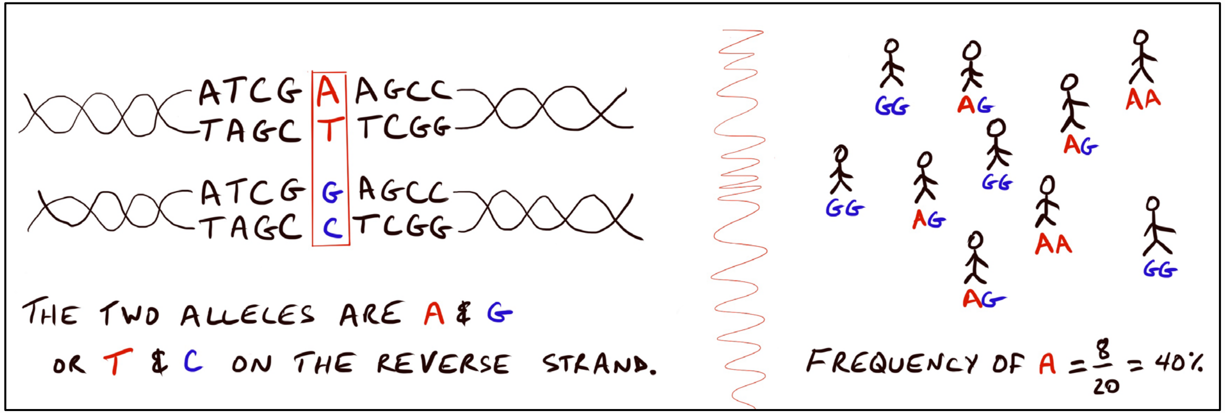
Genome size is not indicative of the number of genes or species complexity.

Alleles



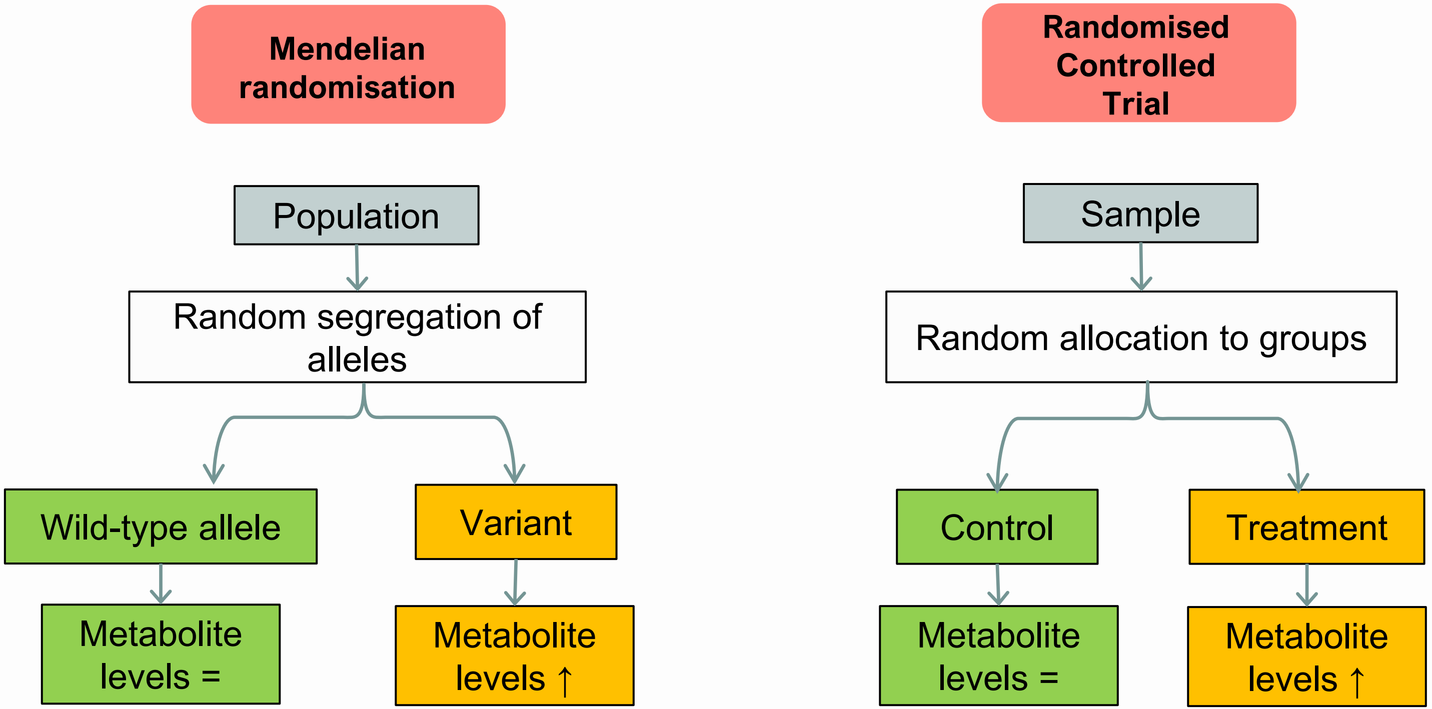
Where the gene is found:	Sequence of bases (starting at position 229):	Protein and trait:
Locus for transducin gene on chromosome 1	. . . CACCAGCAACCC . . .	Transducin protein synthesized, colour vision possible
	. . . CACCAGTAACCC . . .	Protein not formed correctly, colour vision not possible

Single nucleotide polymorphism (SNP)



An allele is one specific form of a gene, differing from other alleles by one or a few bases.

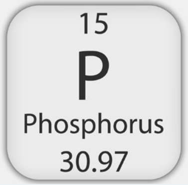
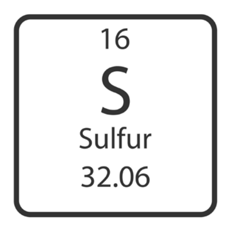
Mendelian randomisation (MR)

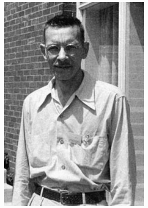


MR draws on Mendel's law of segregation and law of independent assortment to mimic a randomised controlled trial.

What is the hereditary material?

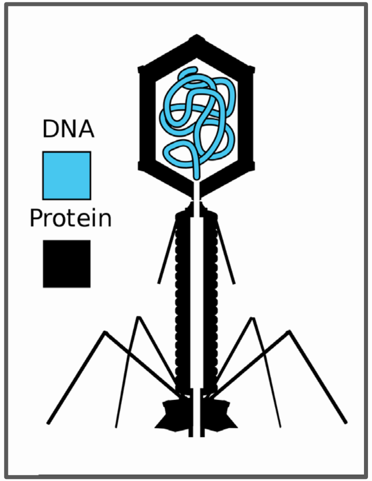
Hershey-Chase experiments (1952)

Element	**Radioisotope:** Isotopes with unstable nuclei that dissipate excess energy in the form of alpha-, beta-, and gamma-ray radiation.
	Phosphorous-32 = 15 protons + 17 neutrons
	Sulfur-35 = 16 protons + 19 neutrons

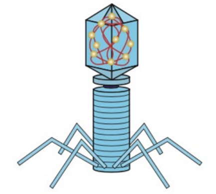


Alfred Hershey
(1908 - 1997)

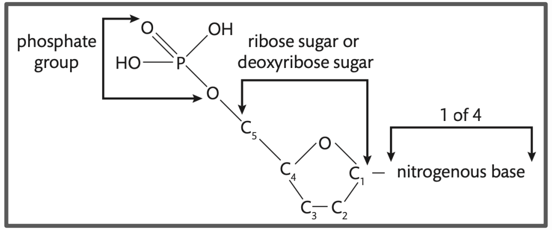
Martha Chase
(1927 - 2003)



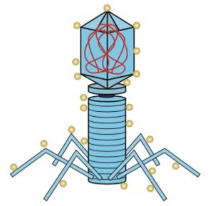
What is the hereditary material? Hershey-Chase experiments (1952)



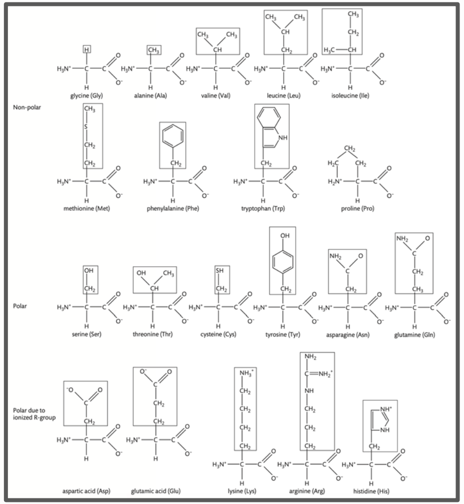
bacteriophage with
phosphorus-32 in DNA



- Phosphorous is contained in DNA, but not amino acids (proteins).

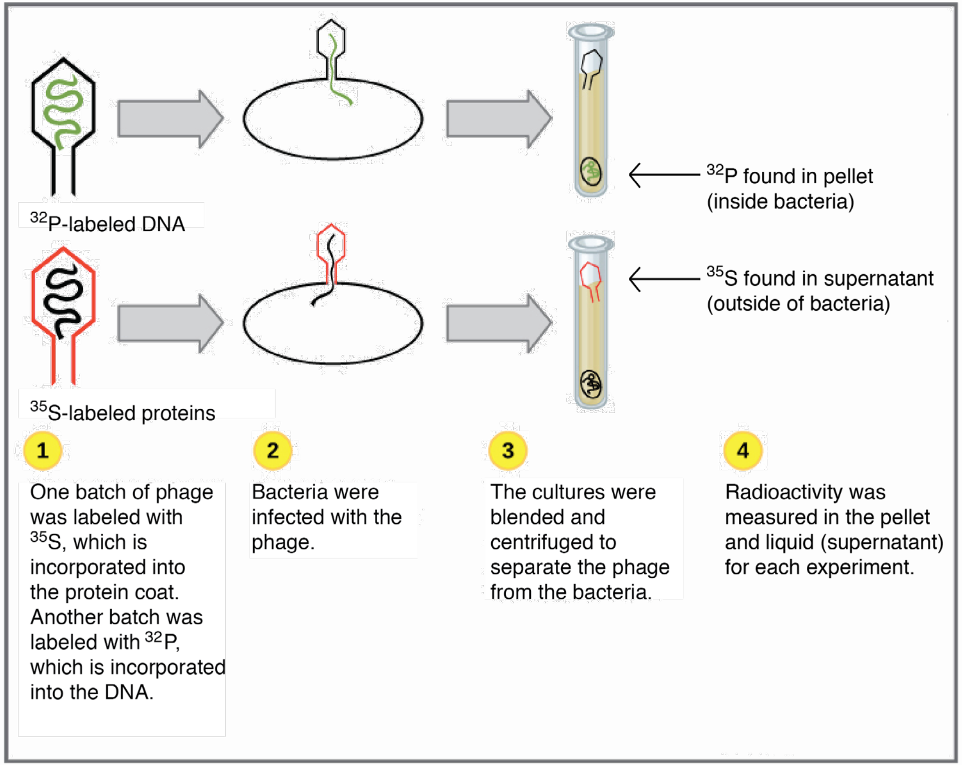


bacteriophage with
sulfur-35 in protein coat



- Sulfur is contained in some amino acids (proteins), but not DNA.

What is the hereditary material? Hershey-Chase experiments (1952)



DNA is the hereditary material that enables the passing of information from parents to offspring.

Learning outcomes

- **Biomedical science**
  - Molecules of life I
    - Atoms and periodicity
    - Carbon
    - Water
    - Carbohydrates
    - Lipids
    - Proteins
  - Molecules of life II
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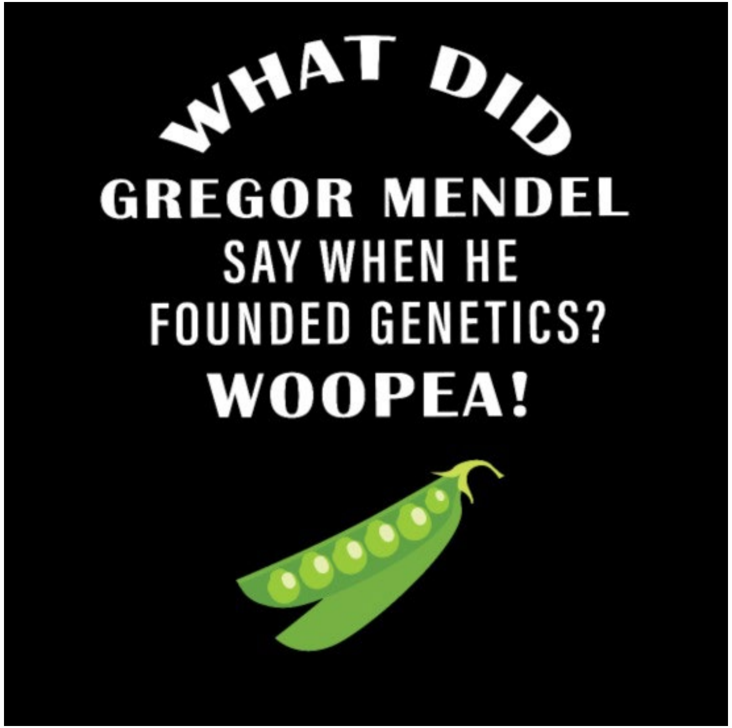
Thank you for listening!



Introduction to Biomedical Science - 3rd Session: Cells

Sonja N. Tang, MSc

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Learning outcomes

- **Biomedical science**
  - Molecules of life I
    - Atoms and periodicity
    - Carbon
    - Water
    - Carbohydrates
    - Lipids
    - Proteins
  - Molecules of life II
    - Nucleic acids
    - DNA and RNA
    - Heredity and genetics
  - Cells
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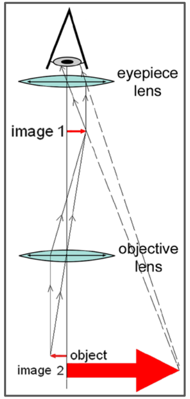
    - Cell cycle
    - Mitosis
    - Meiosis
  - The central dogma I
    - The central dogma
    - Transcription
    - Translation
    - Mutations
  - The central dogma II
    - Gene regulation
    - OMICs Technologies

History of cell theory

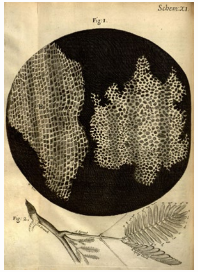
- Spontaneous generation was believed to give rise to life
- **1590:** compound microscopes invented by Hans and Zacharias Jansen, and Hans Lippershey
- **1665:** Robert Hooke introduced the term "cell"
- Antonie van Leeuwenhoek described animal cells and called them "animalcules"
- **1800s:** Cell theory first proposed

Robert Hooke's (1635 – 1703) compound microscope

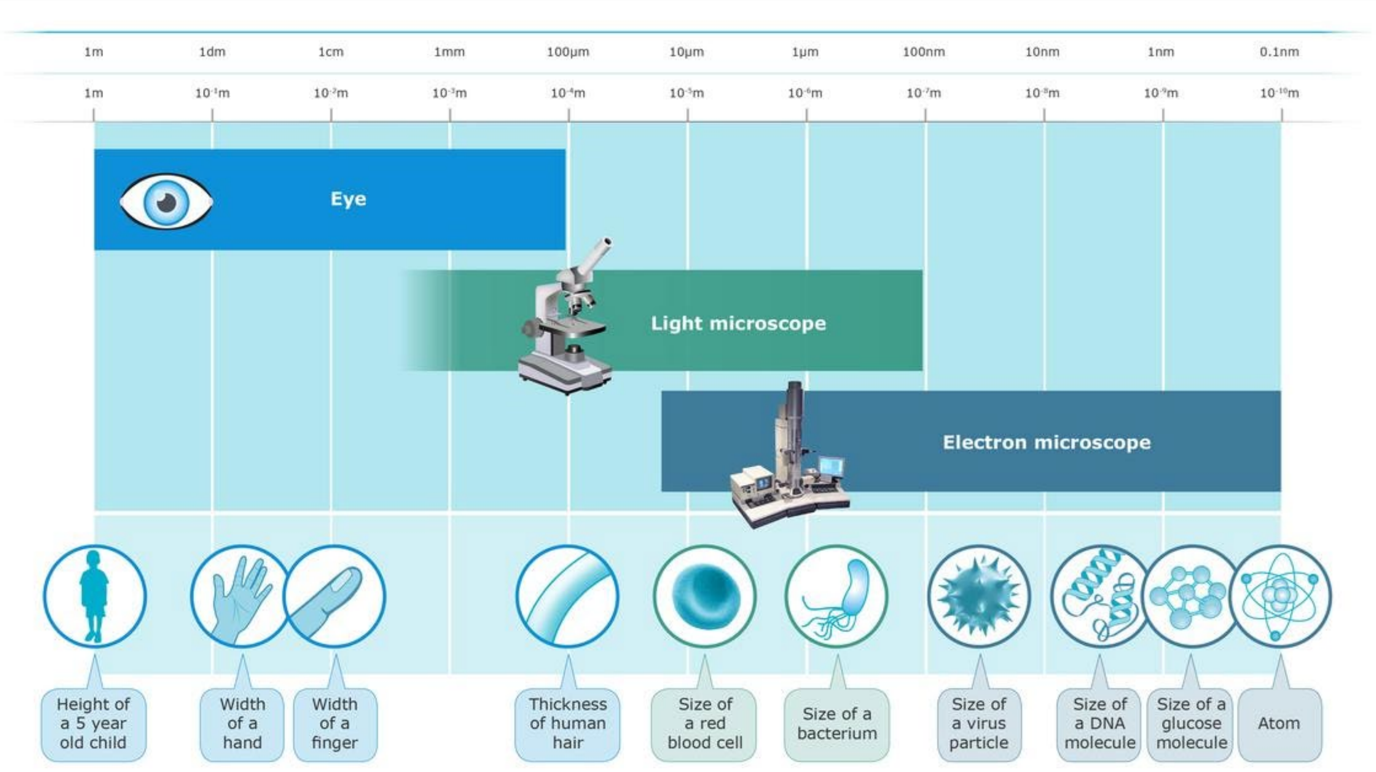
Diagram of a compound microscope.



Drawing of cork and sprig cells



Resolving power of eyes, light microscopes, and electron microscopes



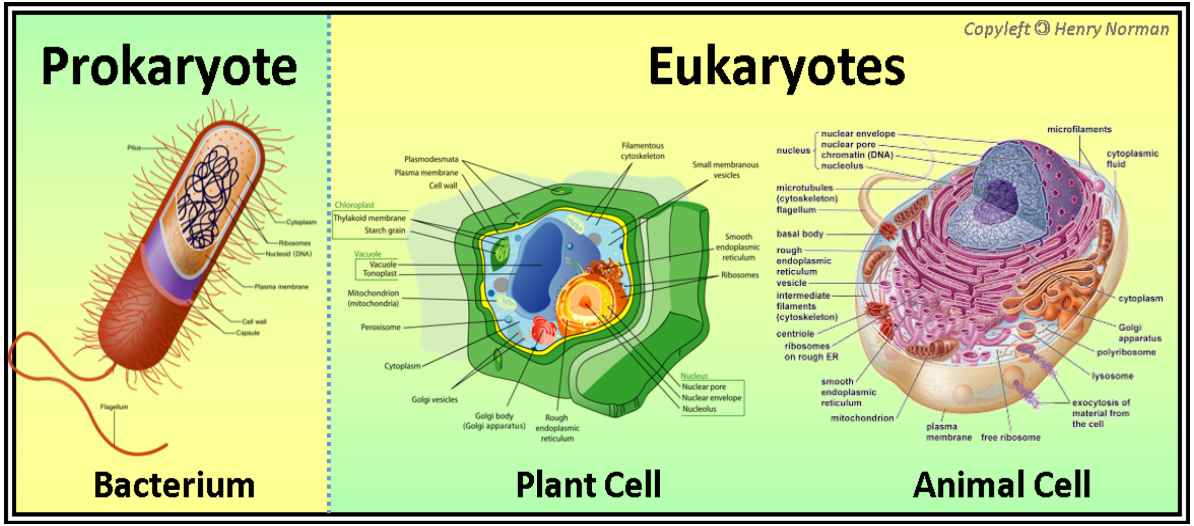
The history of cell theory is inextricably linked to the history of microscopes.

Cell theory

Cell theory

1. All organisms are composed of one or more cells.
2. The cell is the basic unit of life.
3. All cells come from pre-existing cells.

Types of cells



Cell theory provides a framework for understanding the structure, function, and organisation of living organisms.

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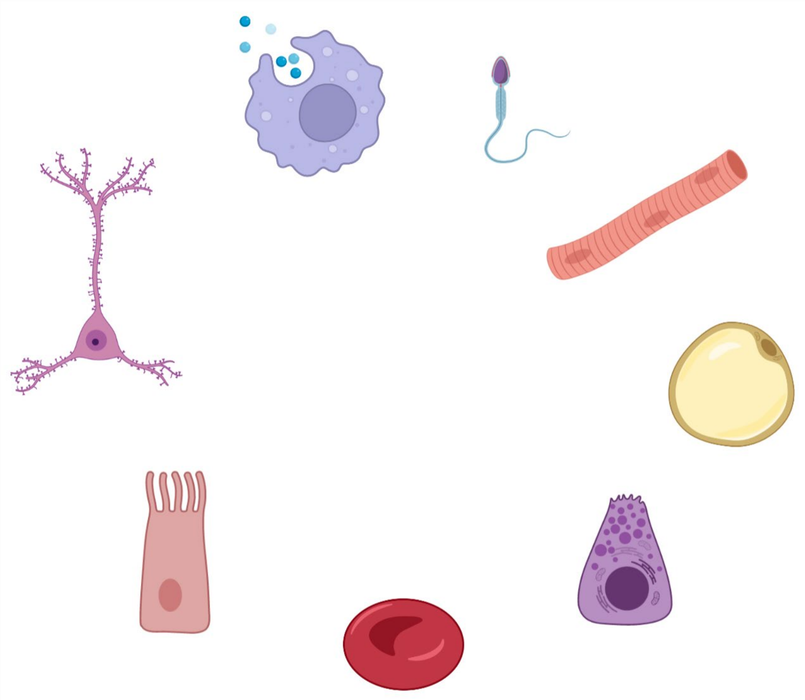
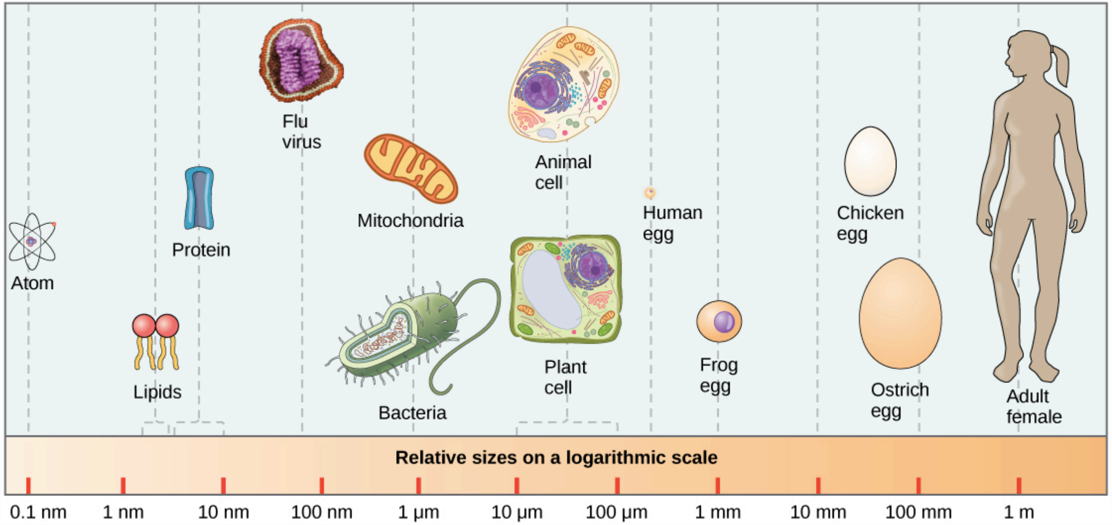
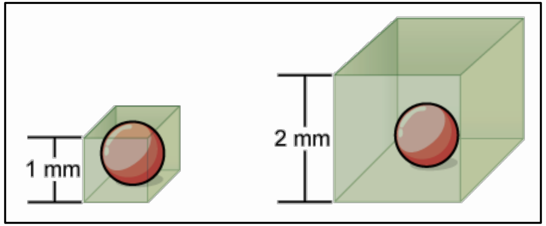
Some examples of animal cells



The flexible cell membrane (as opposed to firm cell walls in plant cells) and the compartmentalisation (as opposed to prokaryotes) of animal cells allows for a diverse array of cells.

Cell size





Surface-area-to-volume ratio:

Left	Right
$6mm^2:1mm^3$	$24mm^2:8mm^3$
6:1	3:1

Cells vary in size from 0.1-100 micrometers, but all need to maintain a high surface-area-to-volume ratio.

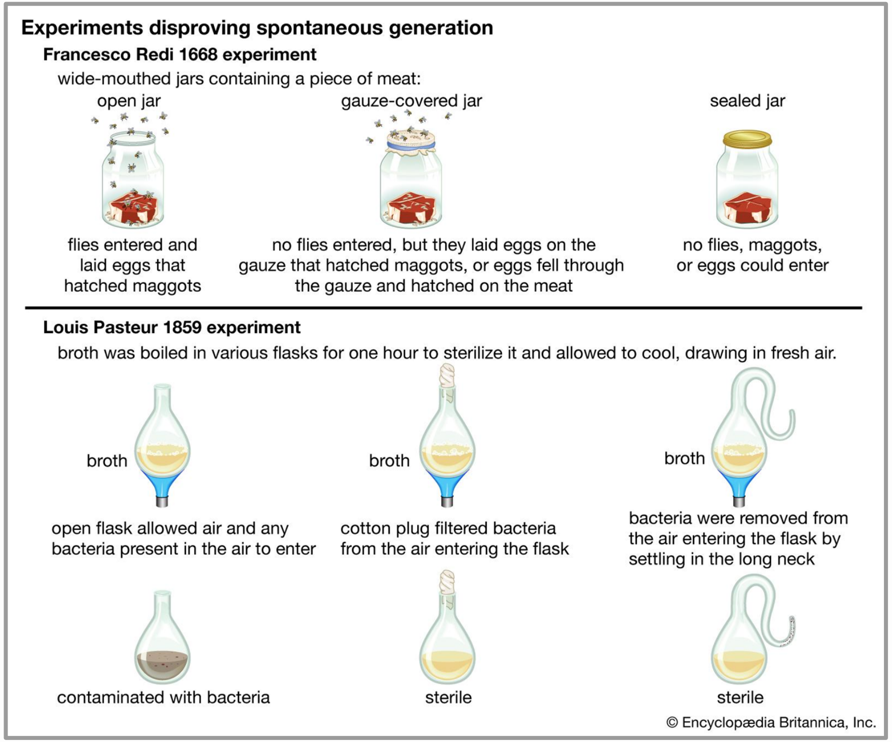
Functions of life

All organisms (unicellular and multicellular) carry out:

1. **Metabolism** – all the chemical reactions that occur within an organism
2. **Growth** – may be limited but still evident
3. **Reproduction** – passing down hereditary molecules to offspring
4. **Response** – response to stimuli in the environment
5. **Homeostasis** – maintenance of a constant internal environment (e.g., temperature, acid-base levels)
6. **Nutrition** – breaking down chemical compounds to provide the organism with the energy necessary to maintain life
7. **Excretion** – release of toxic, harmful, or useless compounds

"Omnis cellula e cellula" ("All cells come from cells")

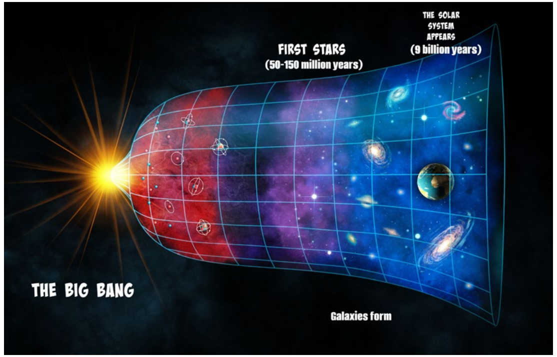
– Rudolph Virchow (1821 – 1902)



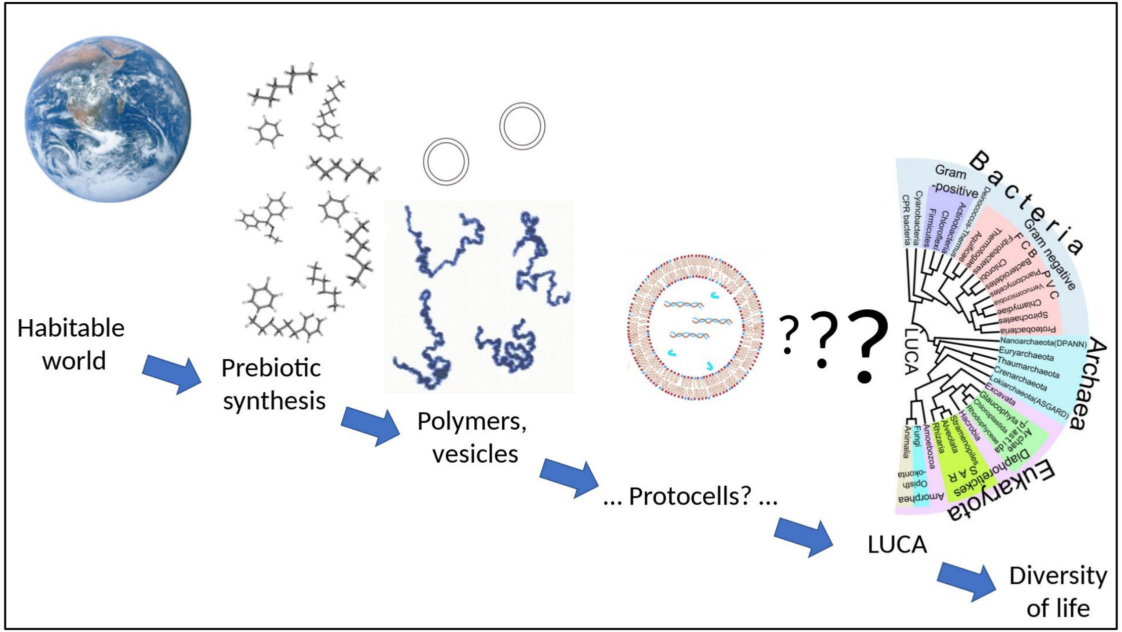
Many scientists have tried, and failed, to prove the spontaneous generation of new cells from non-living material. Hence, we believe new cells must arise from pre-existing cells.

How did the first cells arise?

Big Bang



Visualisation of abiogenesis, or the origin of life.

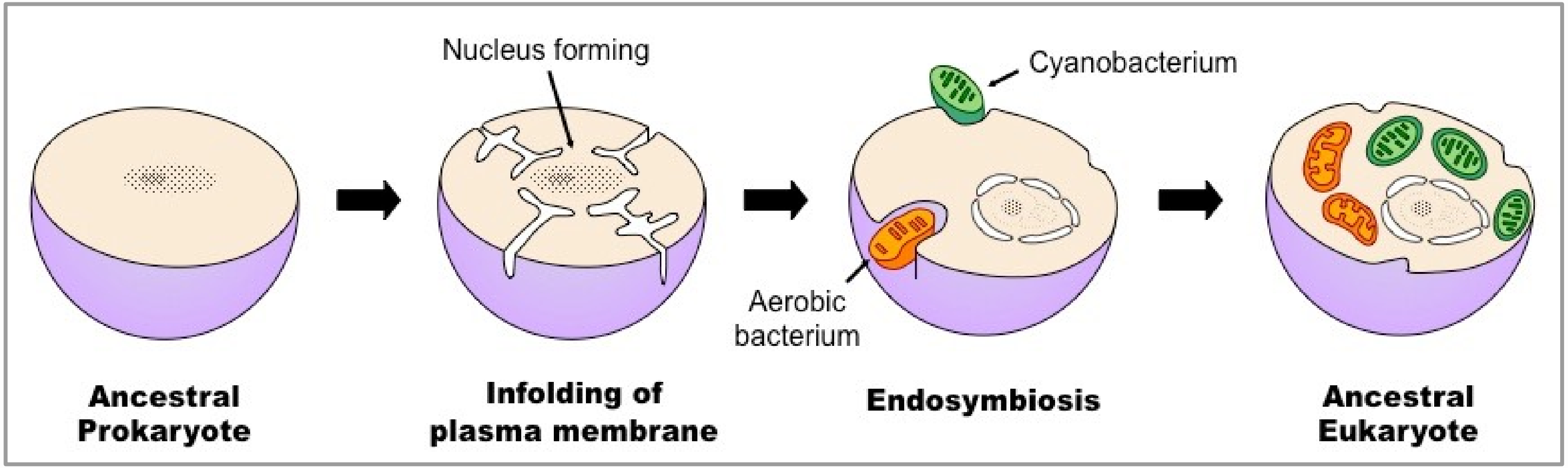


Life arose on the early Earth by a series of progressive chemical reactions. Such reactions may have been likely or may have required one or more highly improbable chemical events.

How did the first eukaryotes arise?

Lynn Margulis (1938 – 2011)

Endosymbiotic theory (1981)



Endosymbiosis is the leading theory of the origin of eukaryotic cells from prokaryotic cells.

Central tenets of cell theory:

1. All organisms are composed of one or more cells.
2. Cells are the smallest units of life.
3. All cells come from pre-existing cells.

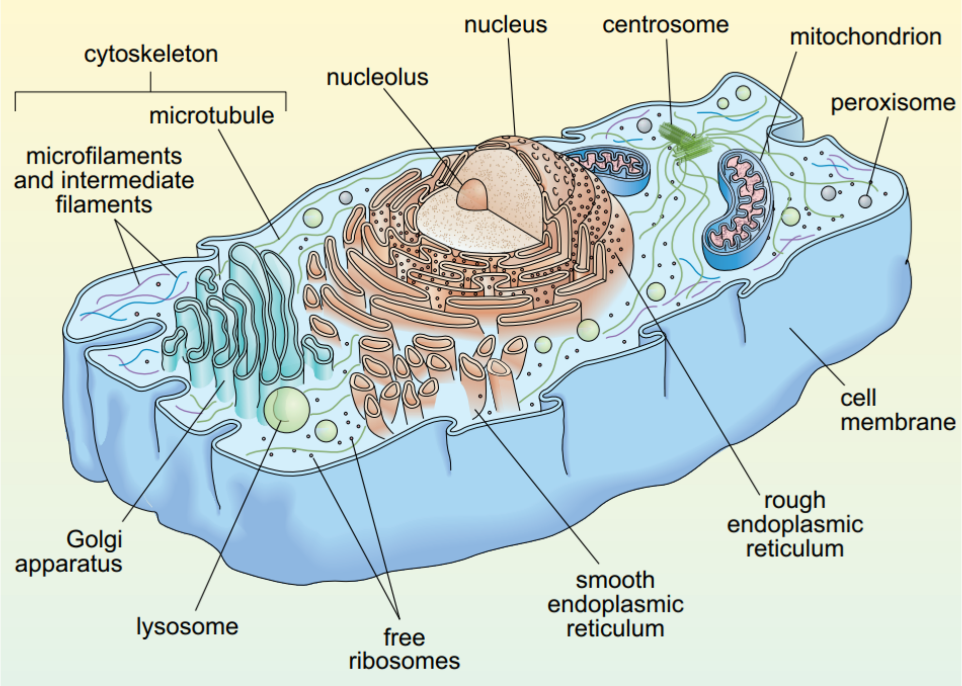
Exceptions:

- Viruses
- Multinucleated cells of striated muscle cells, fungal hyphae, and giant algae
- Very large cells that aren't compartmentalized into smaller cells
- Open question: How do you explain how the first cells arose without spontaneous generation?

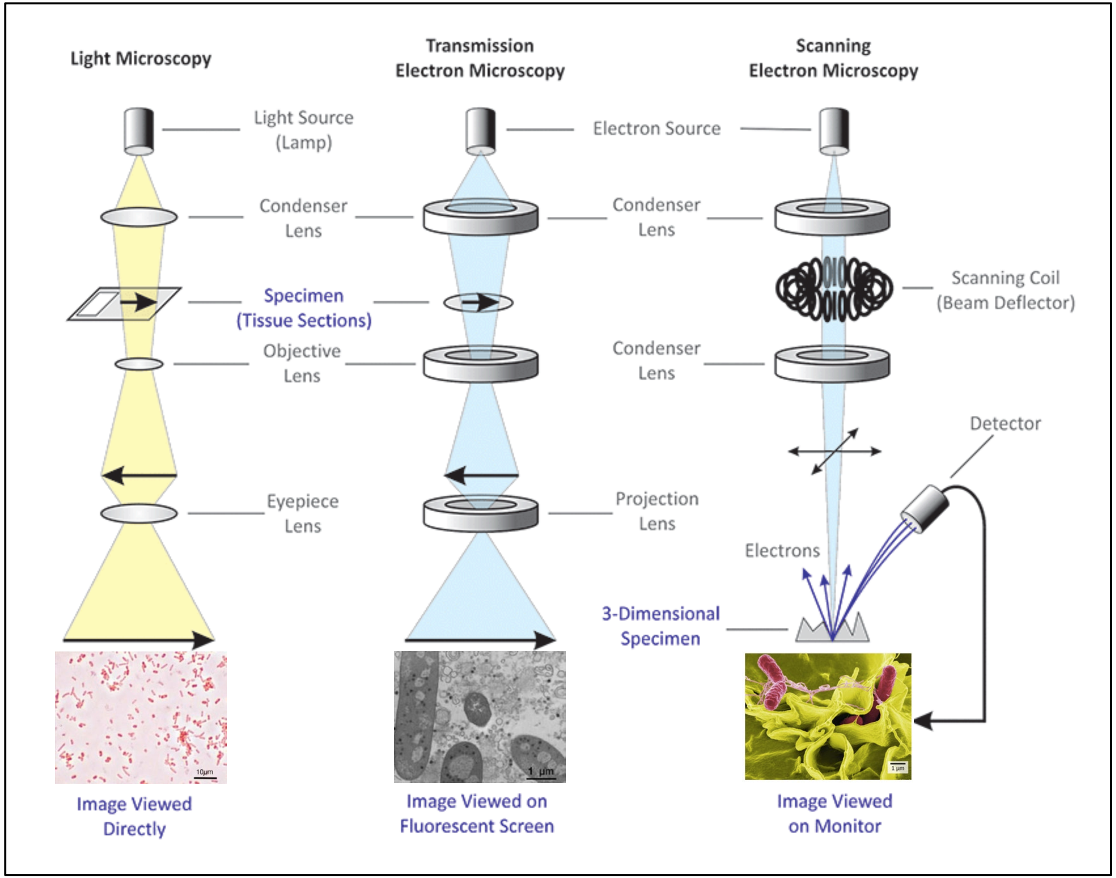
Cell theory is a well-substantiated endpoint but still an active area of research.

Ultrastructure of cells – the fine structure within a cell that can be seen only with the high magnification obtainable with an electron microscope.

Schematic diagram of the ultrastructure of an animal cell with labelled organelles in 3D



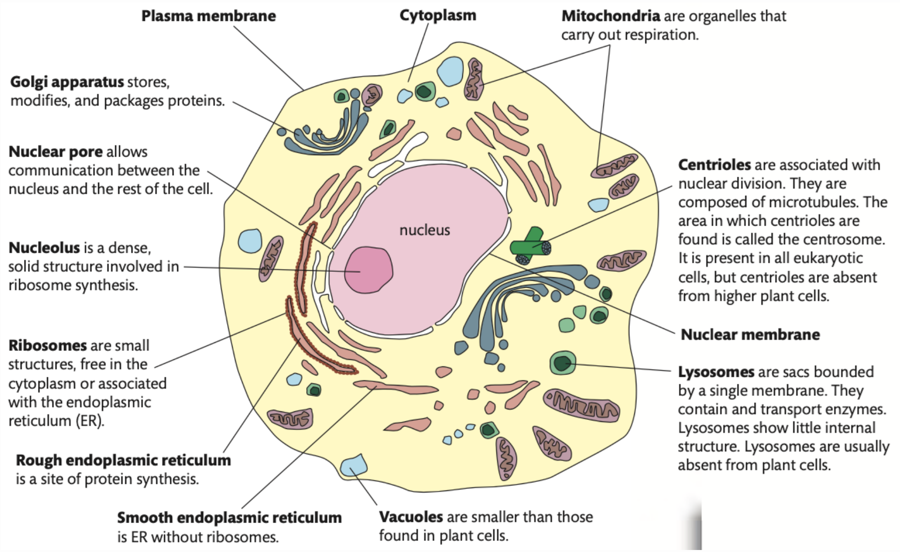
Microscopes



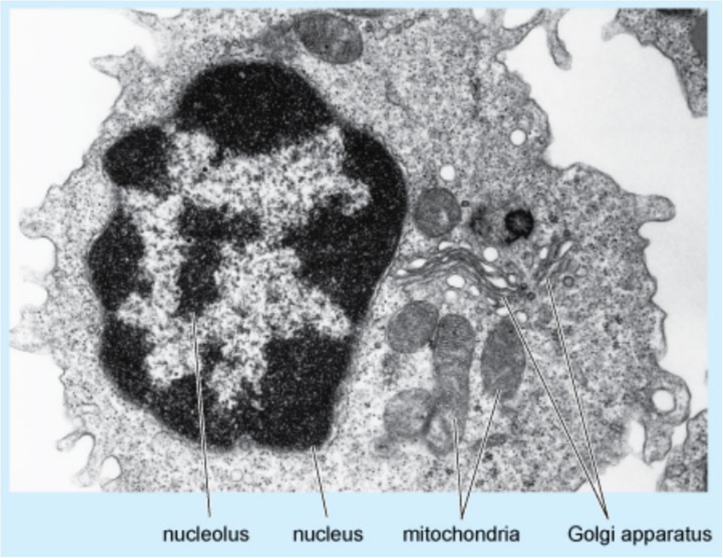
Light microscope magnification: 40x-2,000x. Electron microscope magnification: ~500,000x.

Ultrastructure of animal cells

Schematic diagram of the ultrastructure of an animal cell in 2D showing the various organelles

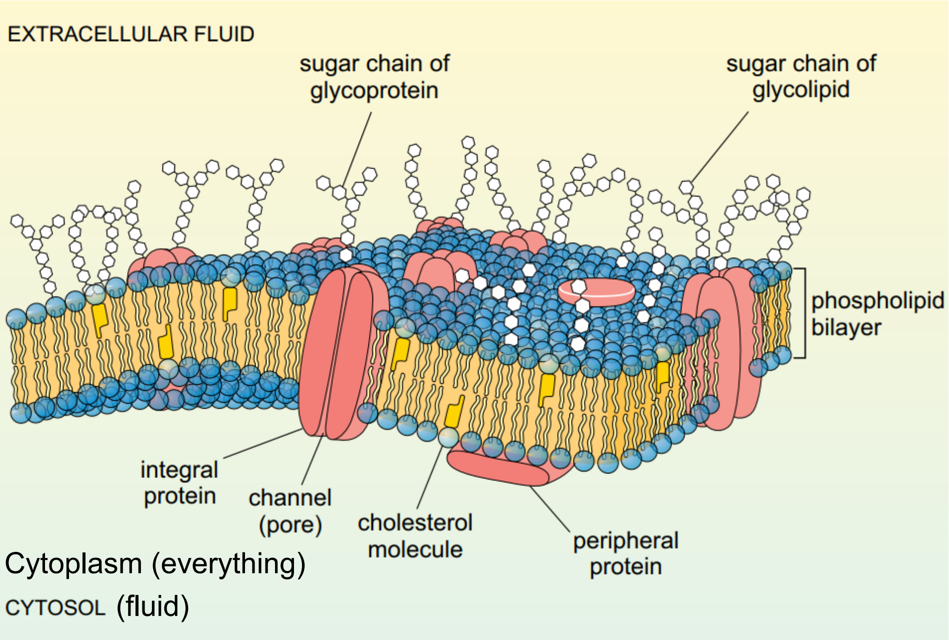


A transmission electron micrograph of a frog leukocyte (white blood cell)

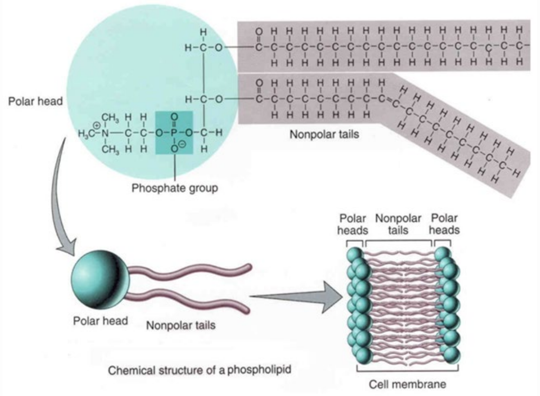


The plasma membrane

Schematic diagram of a plasma membrane

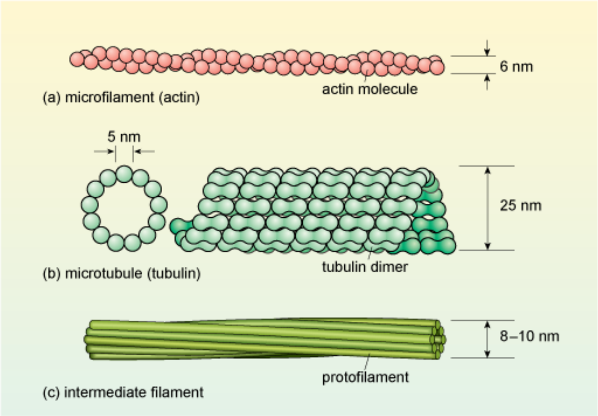


Schematic diagram of a phospholipid

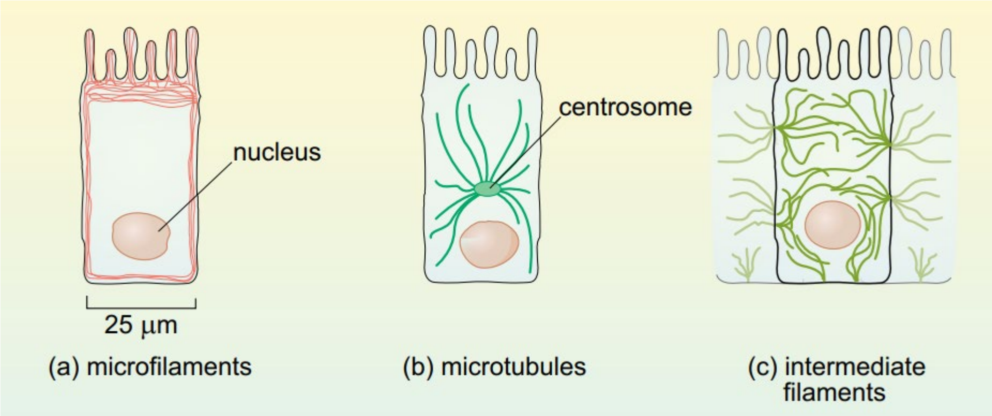


The cytoskeleton

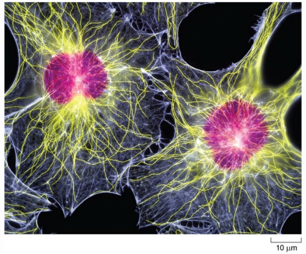
Schematic diagram of the three types of cytoskeletal filaments



Schematic diagram of the three types of filaments as found in cells

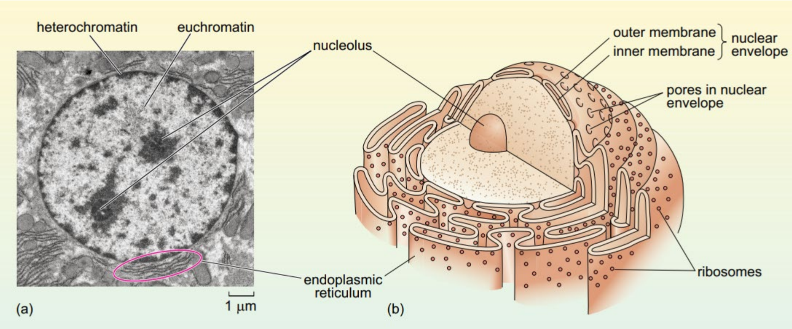


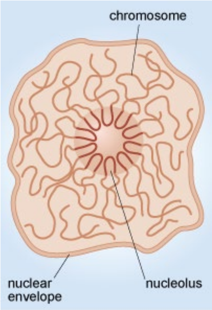
Fluorescent light micrograph of two fibroblasts (connective tissue cells) with nuclei labelled in pink, microtubules in yellow, and microfilaments in blue.



The nucleus

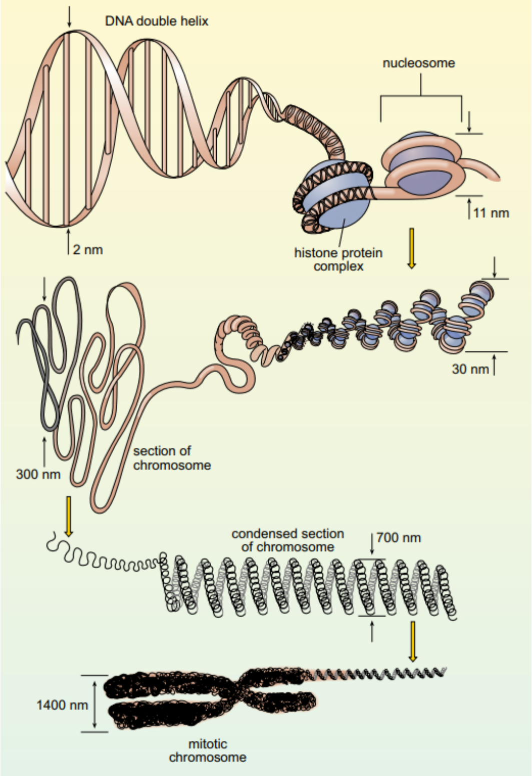
(a) Electron micrograph of the nucleus of a rat liver cell. Heterochromatin and euchromatin can be clearly differentiated as electron-dense (dark) and electron-lucent (pale) areas, respectively. Two electron-dense nucleoli are also visible. (b) Schematic diagram showing the structure of the nucleus, which is linked to the endoplasmic reticulum.





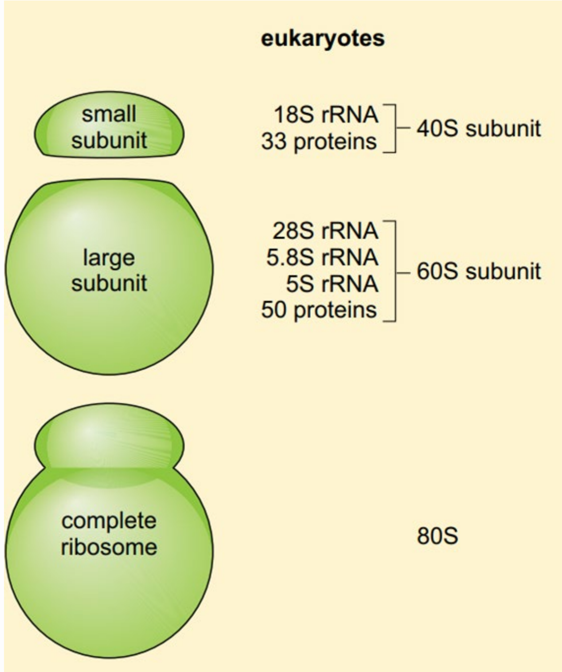
Schematic diagram of the arrangement of chromosomes with respect to the nucleolus.

Schematic diagram of DNA and its packaging into a chromosome

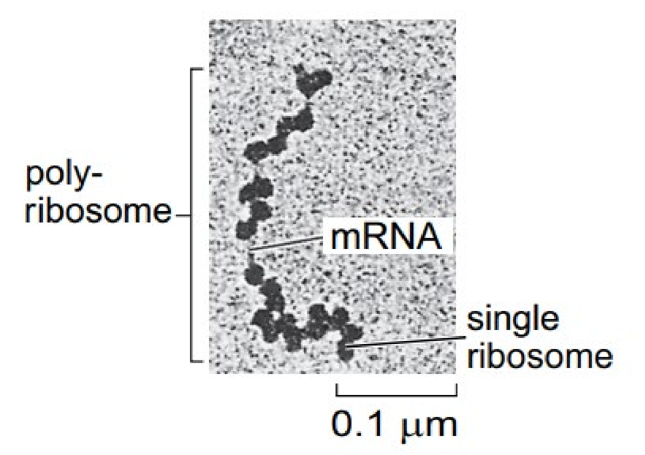


Ribosomes

Schematic diagram of a small and large subunit, and a complete ribosome

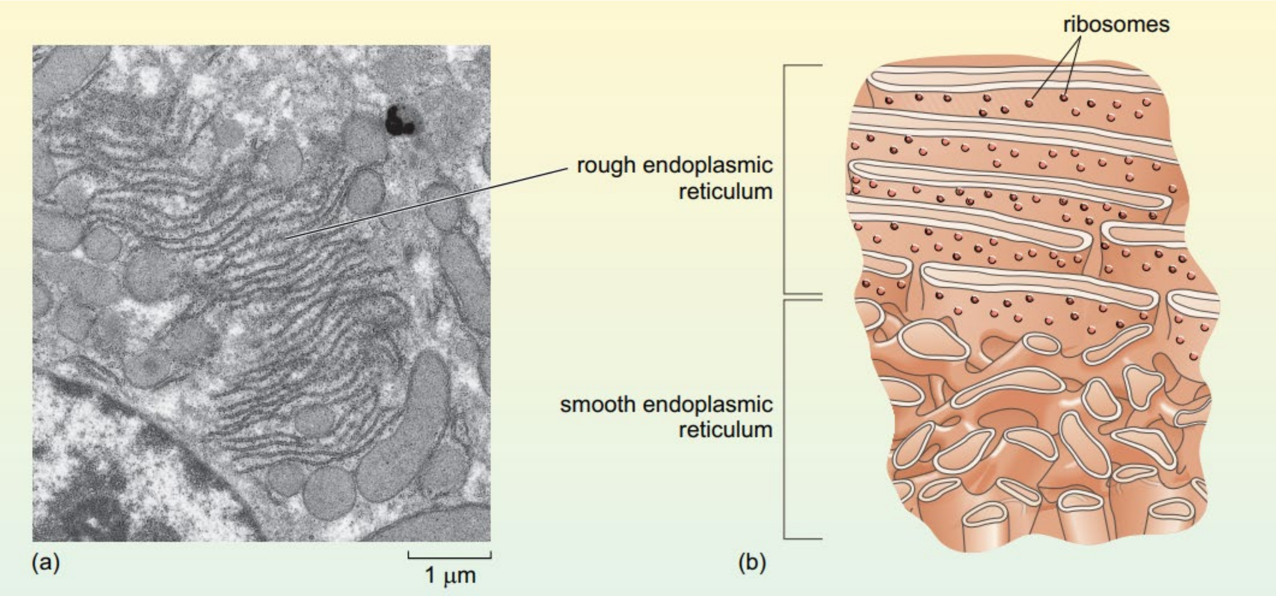


Schematic diagram of 'free' ribosomes attached to newly transcribed mRNA. Several ribosomes joined by an mRNA molecule in this way constitute what is called a polyribosome, or polysome.



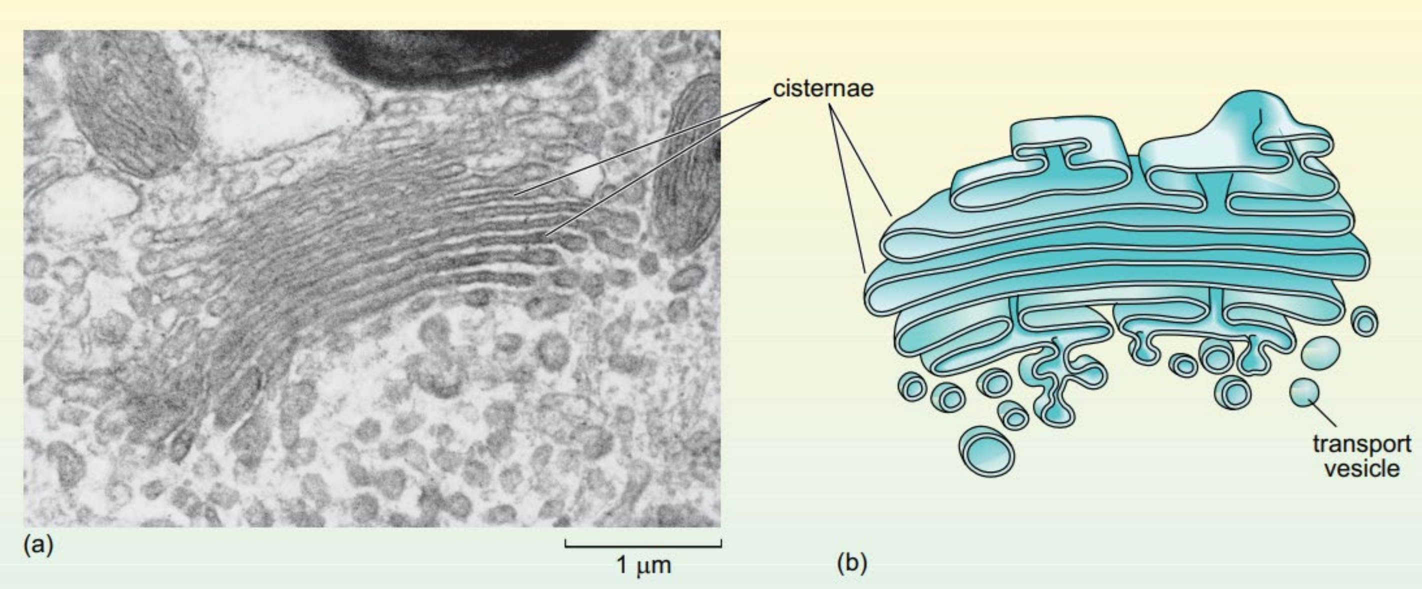
The endoplasmic reticulum

(a) Electron micrograph showing rough endoplasmic reticulum (RER) in a rat liver cell. The granular appearance is due to ribosomes that are attached to the endoplasmic reticulum membrane. (b) Schematic diagram of rough endoplasmic reticulum and smooth endoplasmic reticulum; note that the appearance can be as elongated or spherical tubes, or something in between.



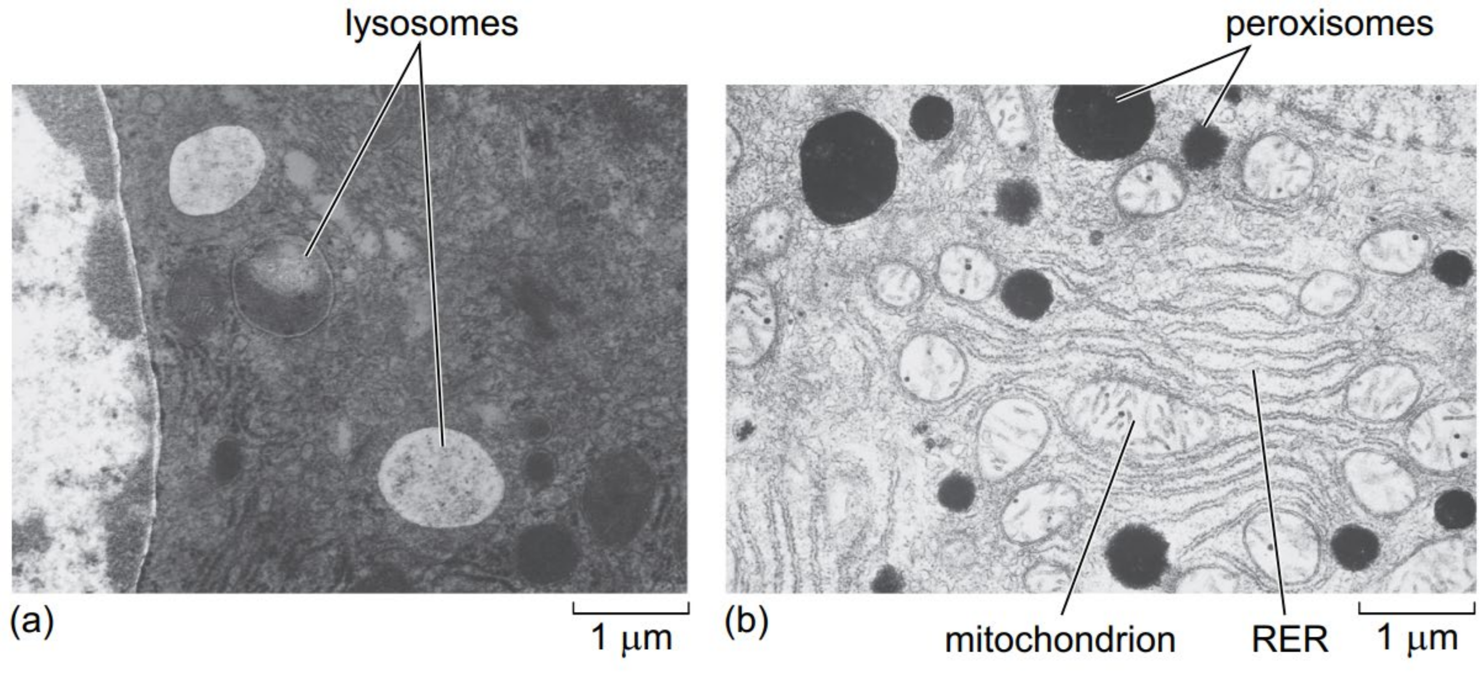
The Golgi apparatus

a) Electron micrograph of the Golgi apparatus from a rat liver cell. The flattened cisternae can be seen. (b) Schematic drawing of the Golgi apparatus, showing the cisternae and associated transport vesicles.



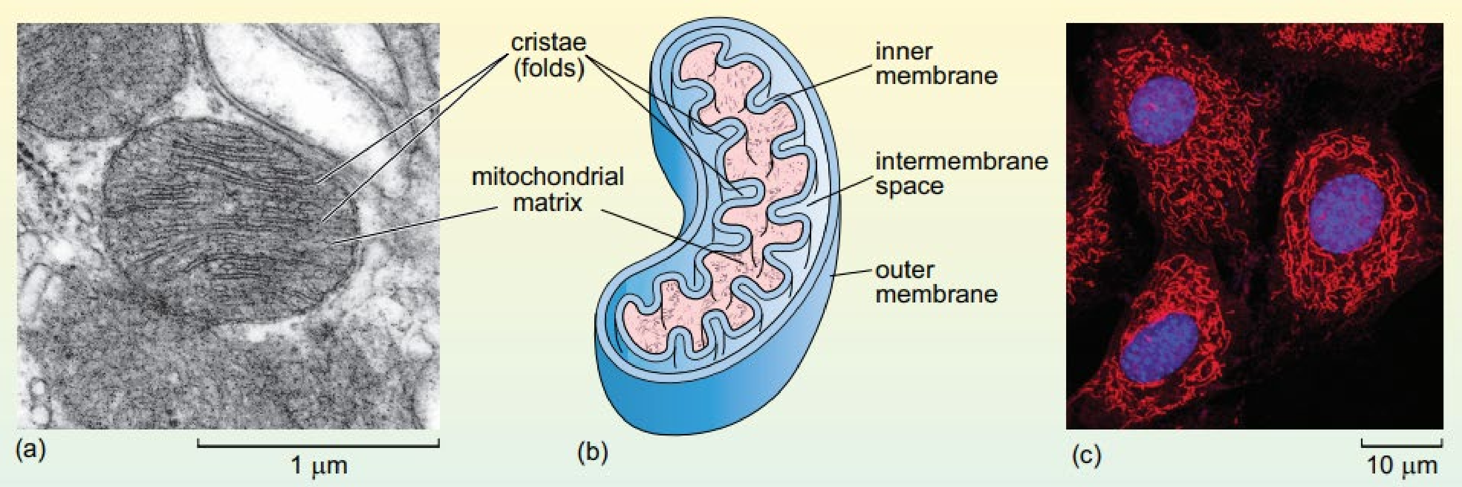
Lysosomes and peroxisomes

Electron micrographs showing (a) lysosomes and (b) peroxisomes (dark-staining structures) seen in liver cells.

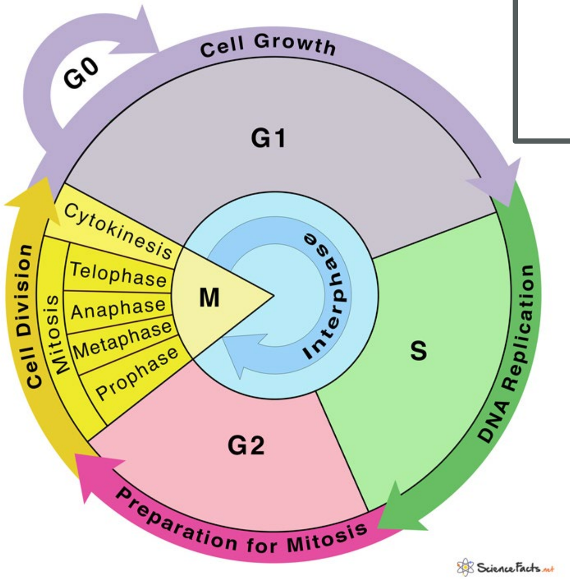


Mitochondria

(a) Electron micrograph of mitochondria from a rat liver cell. The double membrane and cristae are clearly visible. (b) Schematic diagram of a mitochondrion. (c) Fluorescent light micrograph of cultured human cells. The nuclei are labelled blue and the mitochondria red. The image shows the irregular shapes and network-like arrangement of the mitochondria in these cells.

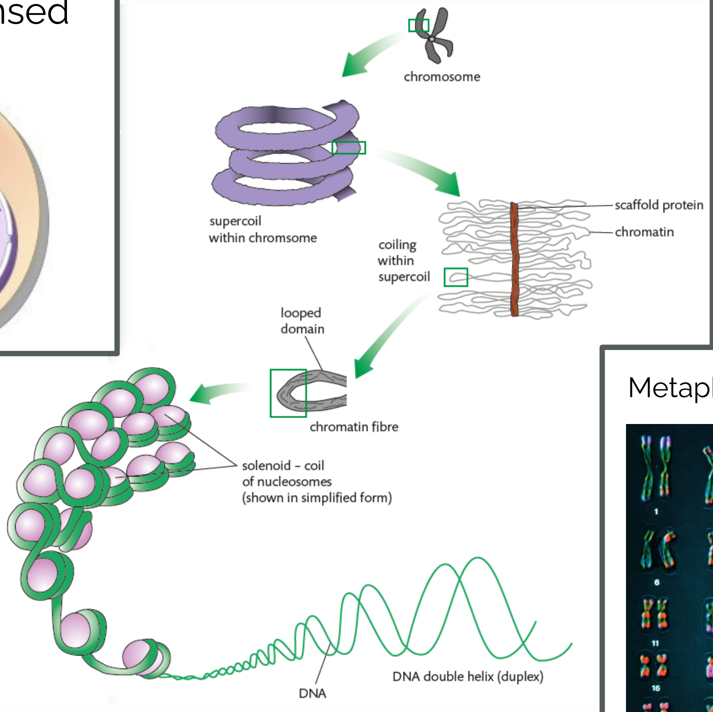


The cell cycle in eukaryotes – The behaviour of cells as they grow and divide.

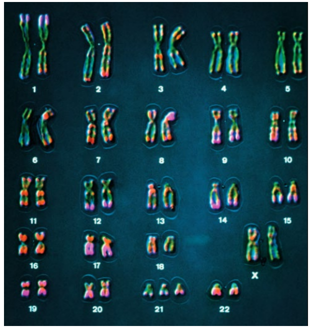


Uncondensed DNA

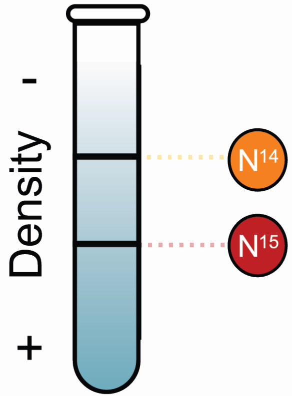
Condensed/packaged DNA



Metaphase Karyogram

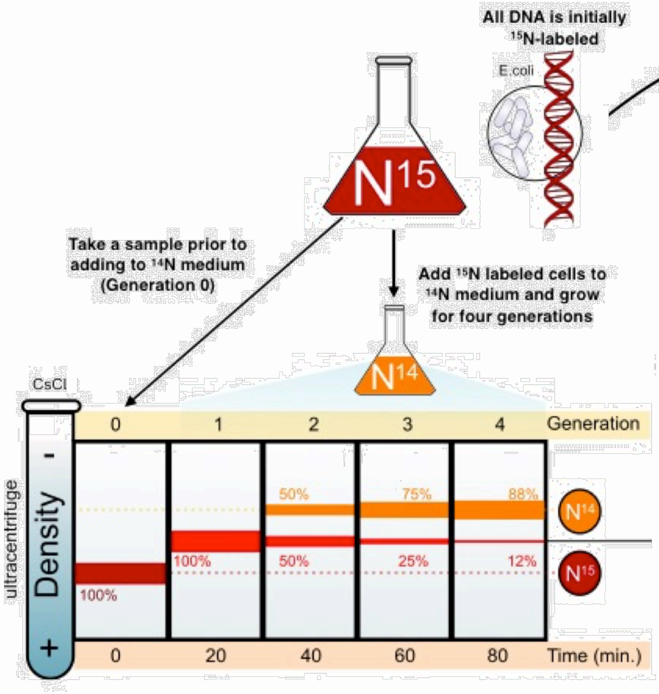


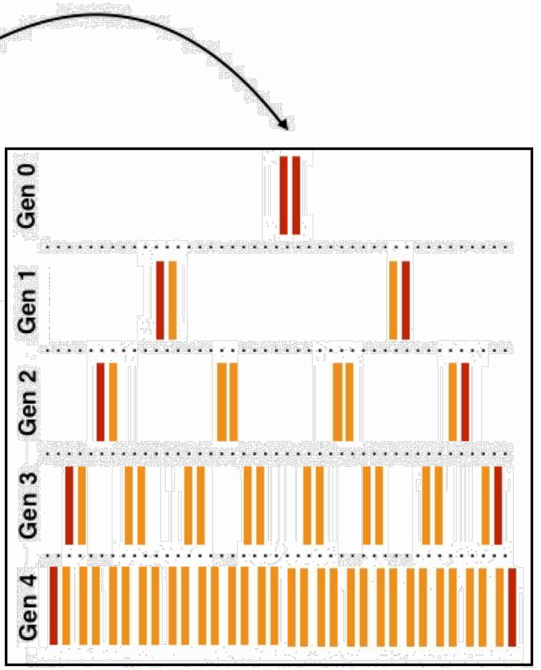
How does DNA replicate? Meselson and Stahl experiment

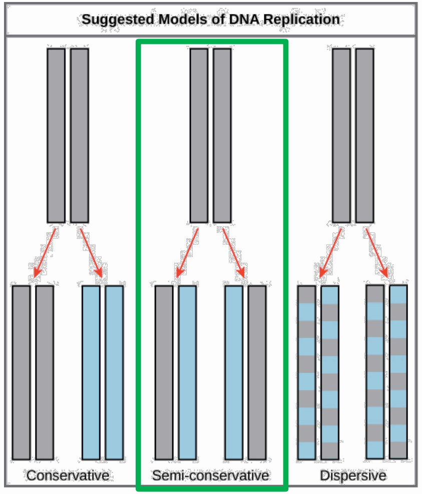


- **Isotope:** “Iso” = same, “tope” = place. Atoms of an element with same atomic number and position in the periodic table but different masses and properties.

How does DNA replicate? Meselson and Stahl experiment







DNA replicates semi-conservatively.

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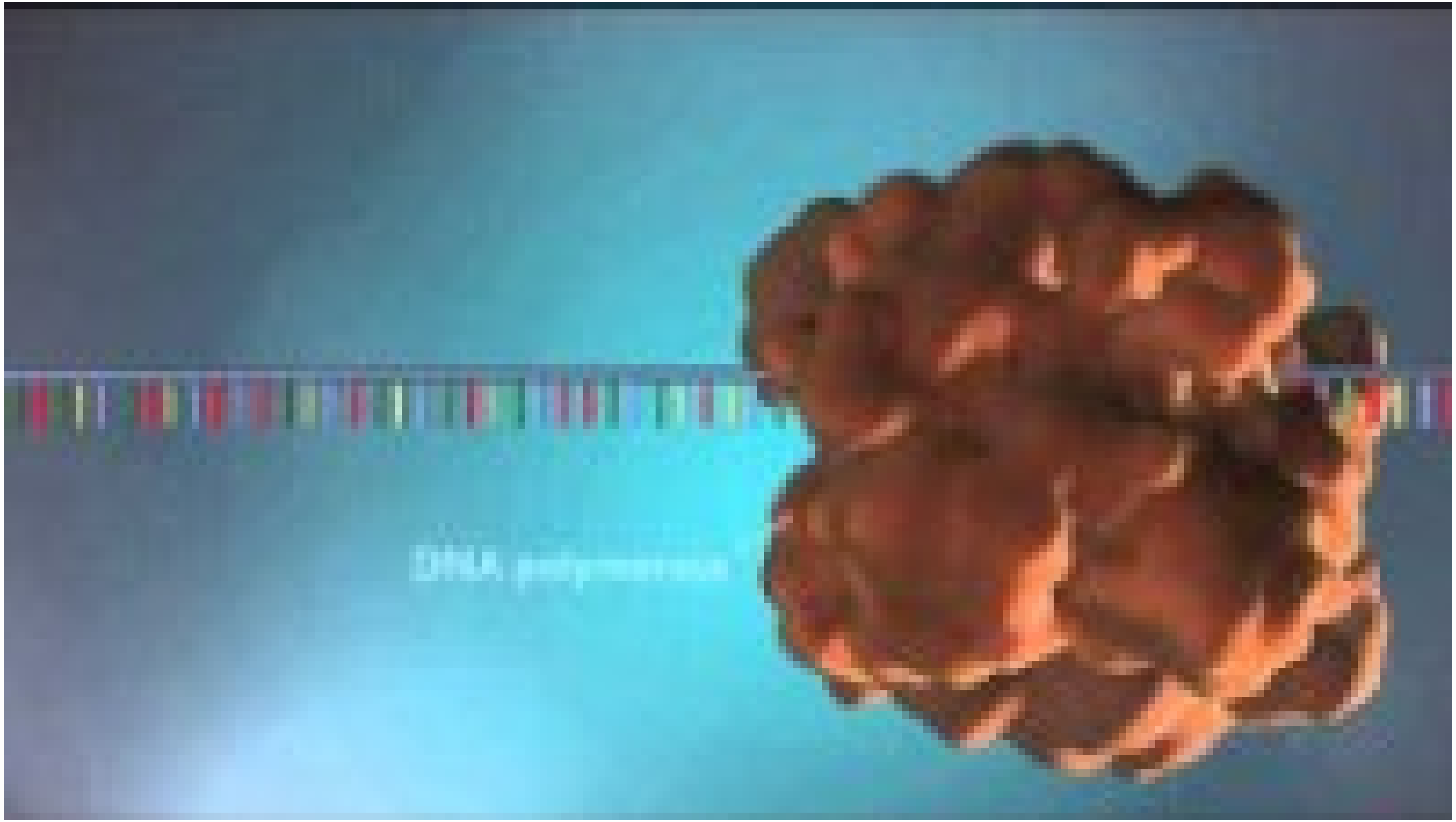
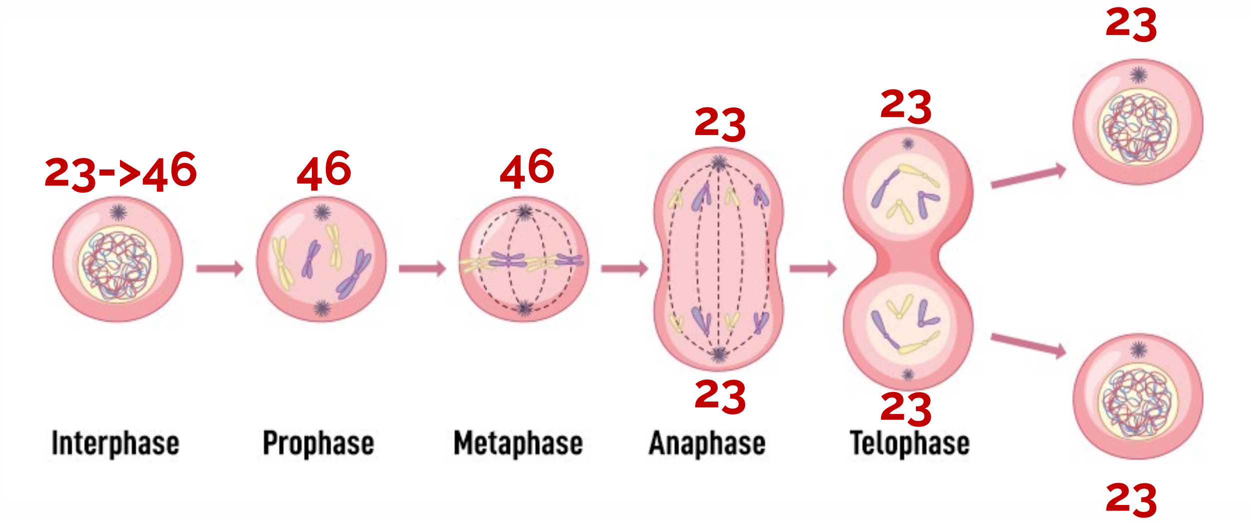
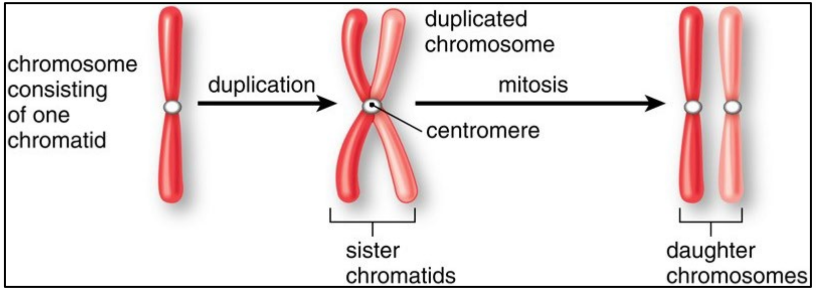
“DNA replication – 3D” by yourgenome

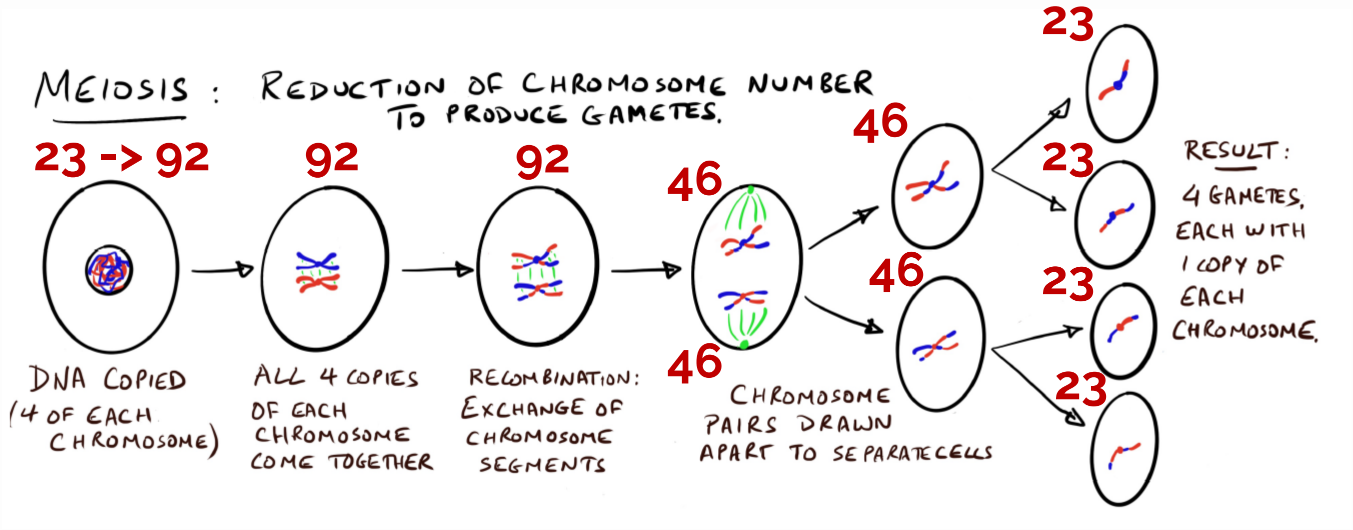


Mitosis - cell division of one parent cell to form two daughter cells

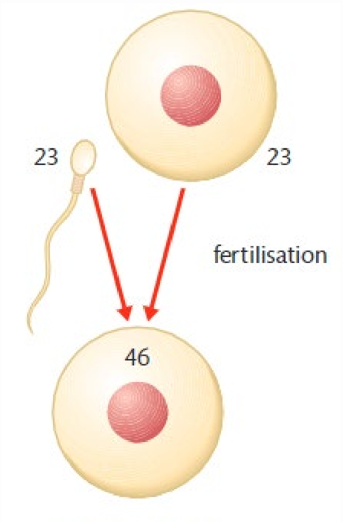




Meiosis – cell division to form gametes

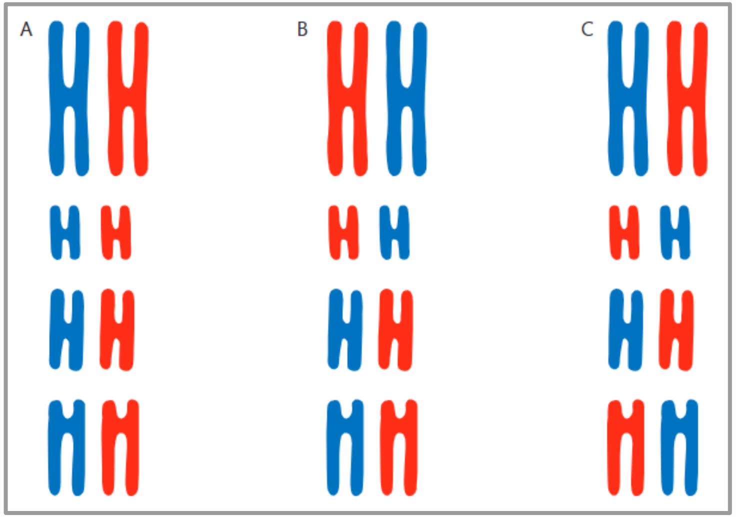


Schematic of fertilisation



Random orientation and homologous recombination (crossing over)

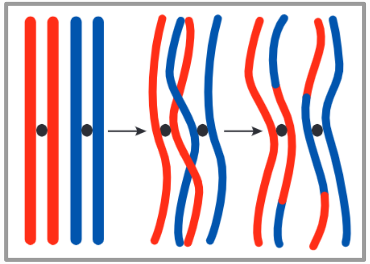
Example of random orientation with combinations of 4 sister chromatids



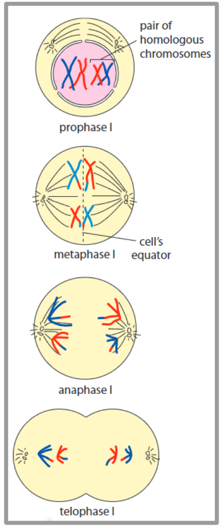
The chance that an identical gamete could be produced is 1 in 2^{23} = ~8 million

Examples of how variation can arise during homologous recombination

Schematic of homologous recombination



Schematic of homologous recombination in a cell



Random orientation and homologous recombination promote genetic variation, giving the species a better evolutionary ability to adapt and survive.

Learning outcomes

- **Biomedical science**
  - Molecules of life I
    - Atoms and periodicity
    - Carbon
    - Water
    - Carbohydrates
    - Lipids
    - Proteins
  - Molecules of life II
    - Nucleic acids
    - DNA and RNA
    - Heredity and genetics
  - Cells
    - Cell theory
    - Ultrastructure
    - Cell cycle
    - Mitosis
    - Meiosis
  - The central dogma I
    - The central dogma
    - Transcription
    - Translation
    - Mutations
  - The central dogma II
    - Gene regulation
    - OMICs Technologies

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Thank you for listening!

Email: sonja.tang19@imperial.ac.uk

Introduction to Biomedical Science - 4th Session: The Central Dogma I

Sonja N. Tang, MSc

(sonja.tang19@imperial.ac.uk)

Learning outcomes

- **Biomedical science**
  - Molecules of life I
    - Atoms and periodicity
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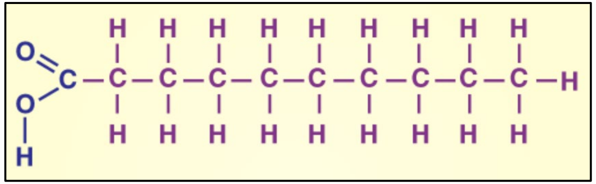
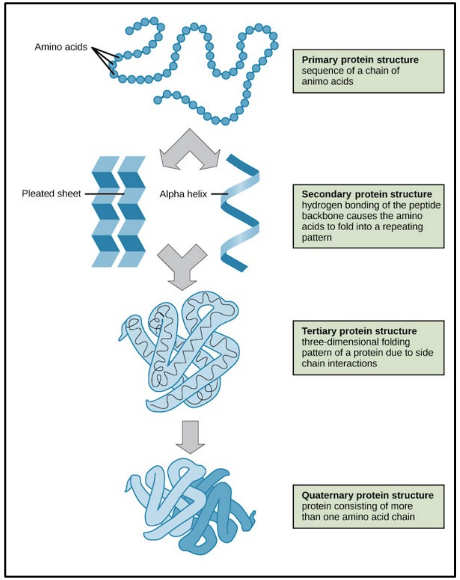
The central dogma

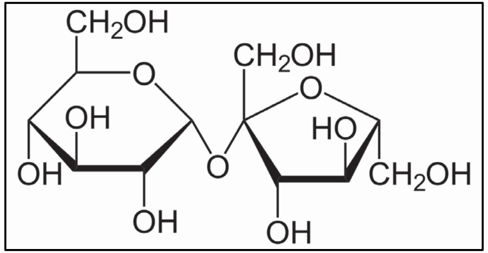
Lipids



Proteins



Carbohydrates



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A recipe to make a dish

Rajma Chawal - Rajma Chawal consists of red kidney beans (rajma) in a spiced tomato gravy, and is served with rice.

Prep - 5 min Cook - 50 min Serves - 2 to 3

Ingredients

To soak kidney beans,

- 1 cup kidney beans
- 4 cups water

To pressure-cook,

- 1 bay leaf
- 1 black cardamom
- 3 green cardamoms
- 3 cloves
- 1 cinnamon stick
- ½ teaspoon salt
- 2 cups water

To blend tomatoes,

- 4 medium tomatoes, quartered
- 2 green chilies, halved
- 2-inch piece ginger, halved
- 4 garlic cloves

A molecular recipe to make a human

Taylor Swift

Taylor – consists of carbohydrates, lipids, and proteins in water, which are packaged in cells.

Eat – 30 min **Digest – 2 hours**
Build proteins – 2 hours

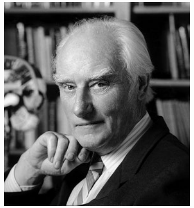
Ingredients to build new proteins from food:

To transcribe DNA,
- Enzymes
- Nucleotides

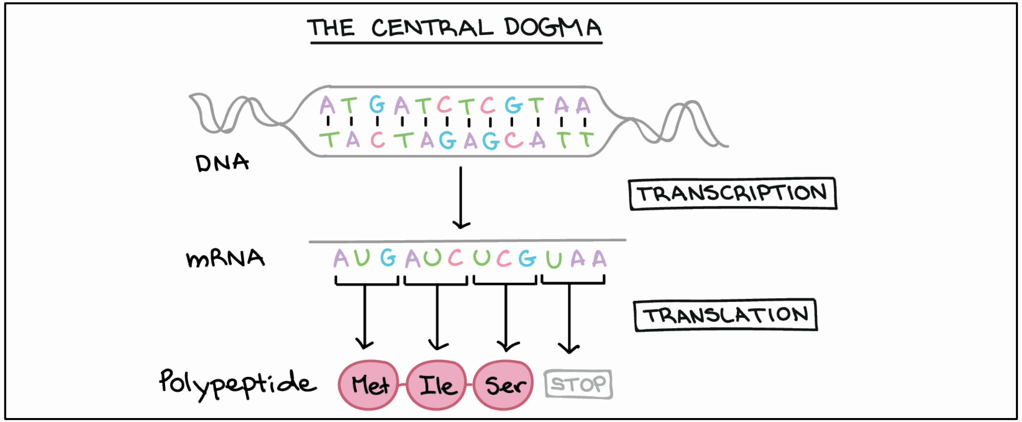
To translate mRNA,
- Ribosomes
- tRNA
- Amino acids

The Central Dogma: DNA -> RNA -> proteins

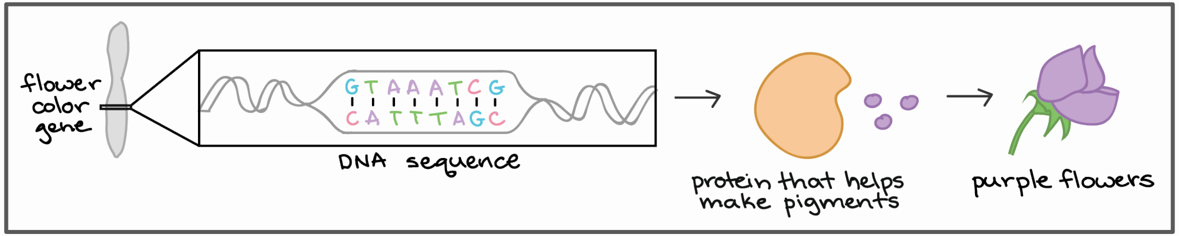
A dogma is something held **as an established opinion**; especially a **definite authoritative tenet**.



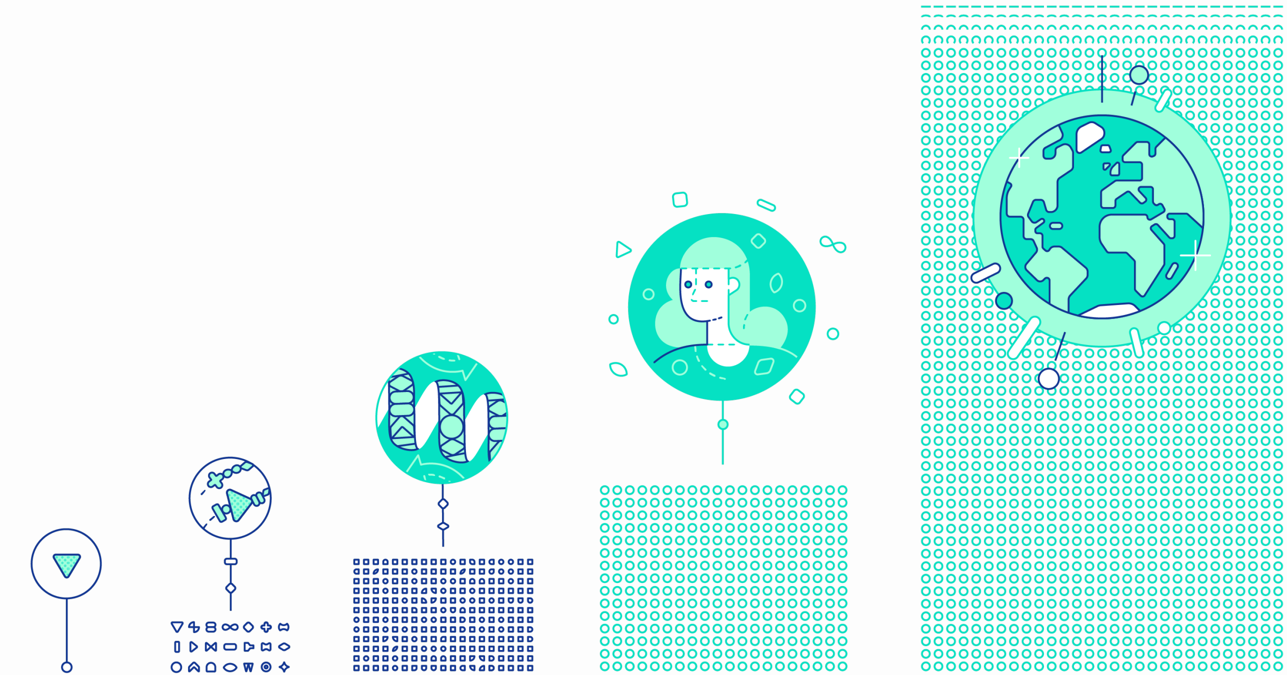
Francis Crick
(1916-2004)



Schematic of gene expression



Protein numbers

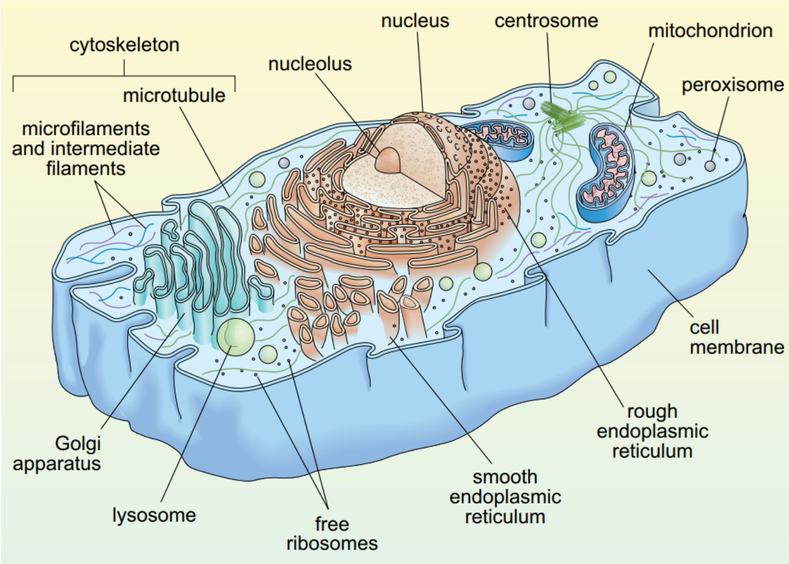


Each person has a unique proteome consisting of ~20,000 proteins.

The Central Dogma

https://youtu.be/8_f-8ISZ164

Where are proteins made?



- Transcription happens in the nucleus.
- Translation of proteins destined for within the cell happens on free ribosomes.
- Translation of proteins destined for the cell membrane or export happens on ribosomes on the endoplasmic reticulum.

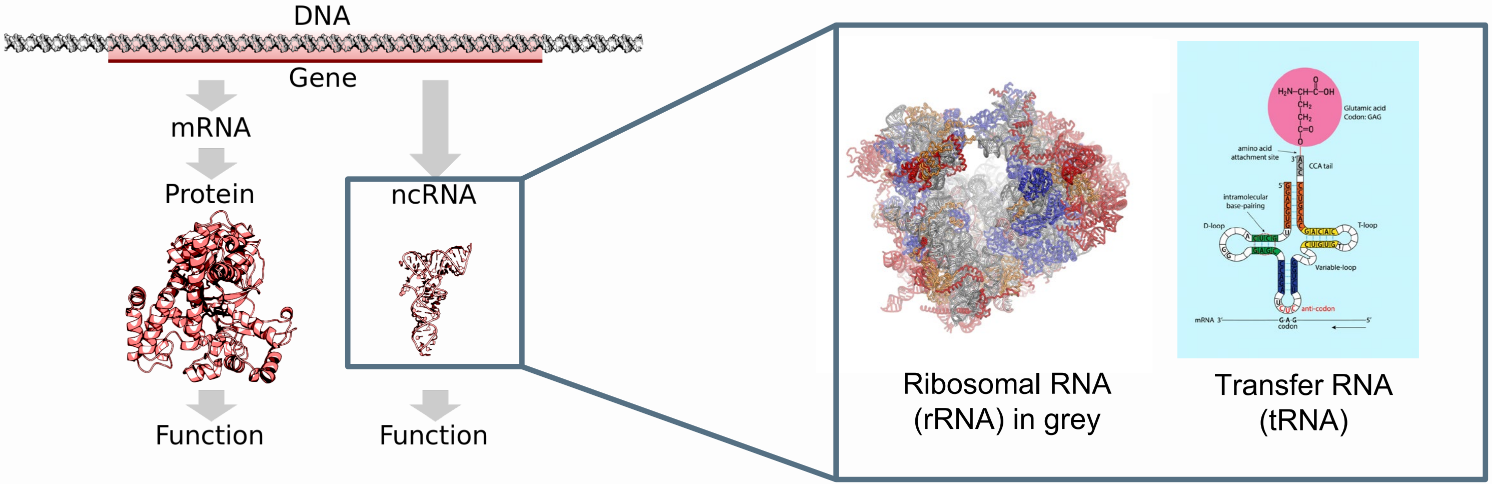
Transcription: DNA -> RNA

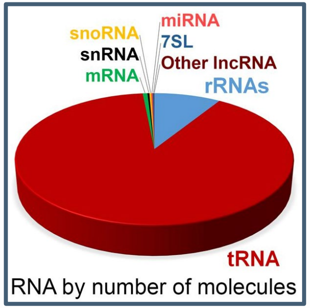
Composition of DNA (3.1 billion bases):

Coding DNA	Non-coding DNA (DNA that is not translated into proteins)
Protein-coding genes (1%)	Regulatory sequences (10%)
	Remaining 89%: • Highly repetitive sequences (e.g. Alu) • Structural DNA • Short tandem repeats

The vast majority of transcription does not lead to proteins.

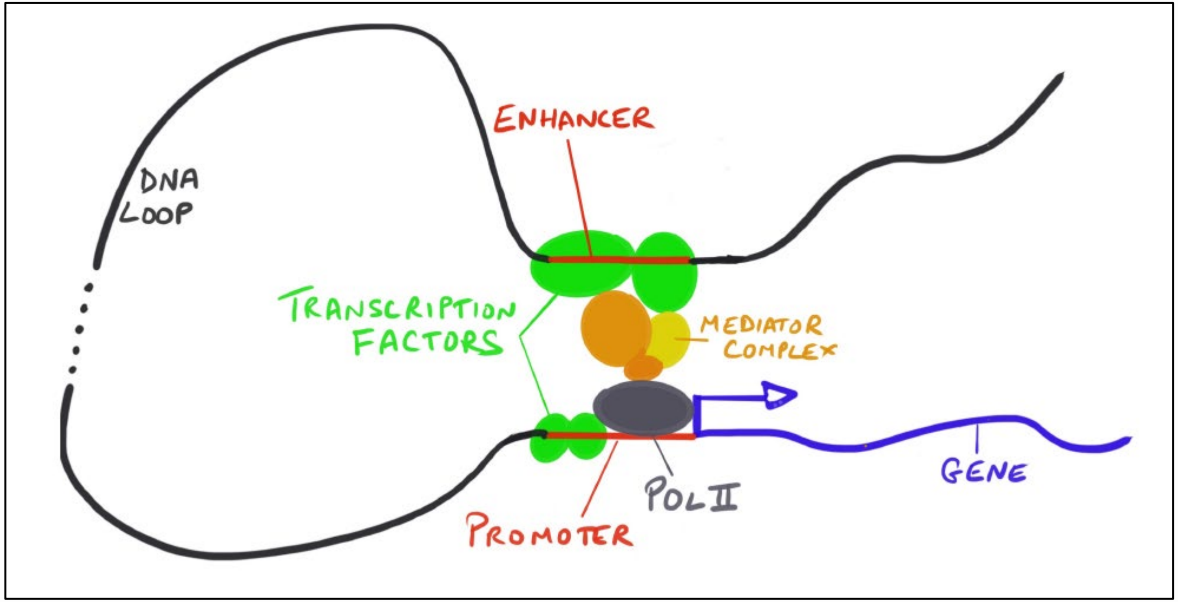
Transcription: DNA -> RNA



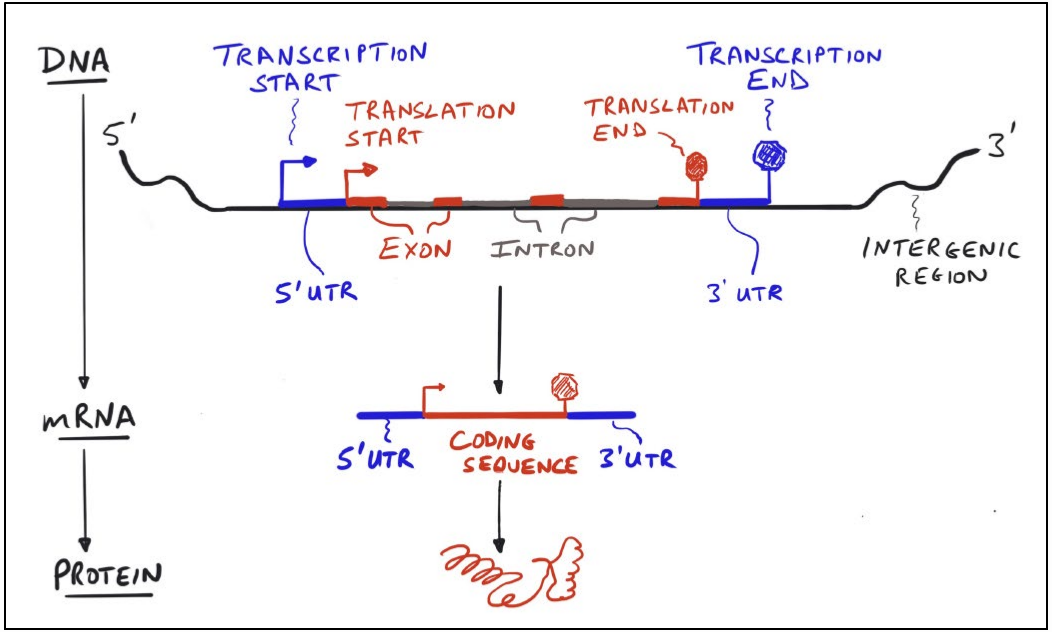


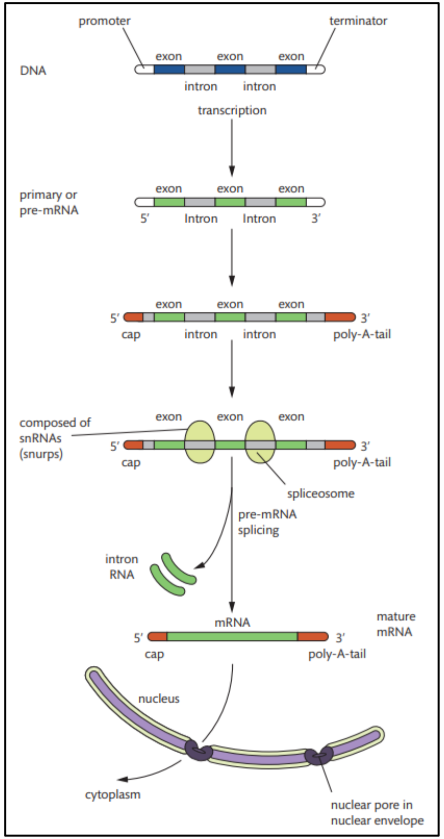
The vast majority of synthesised RNA is tRNA.

Transcription: DNA -> RNA

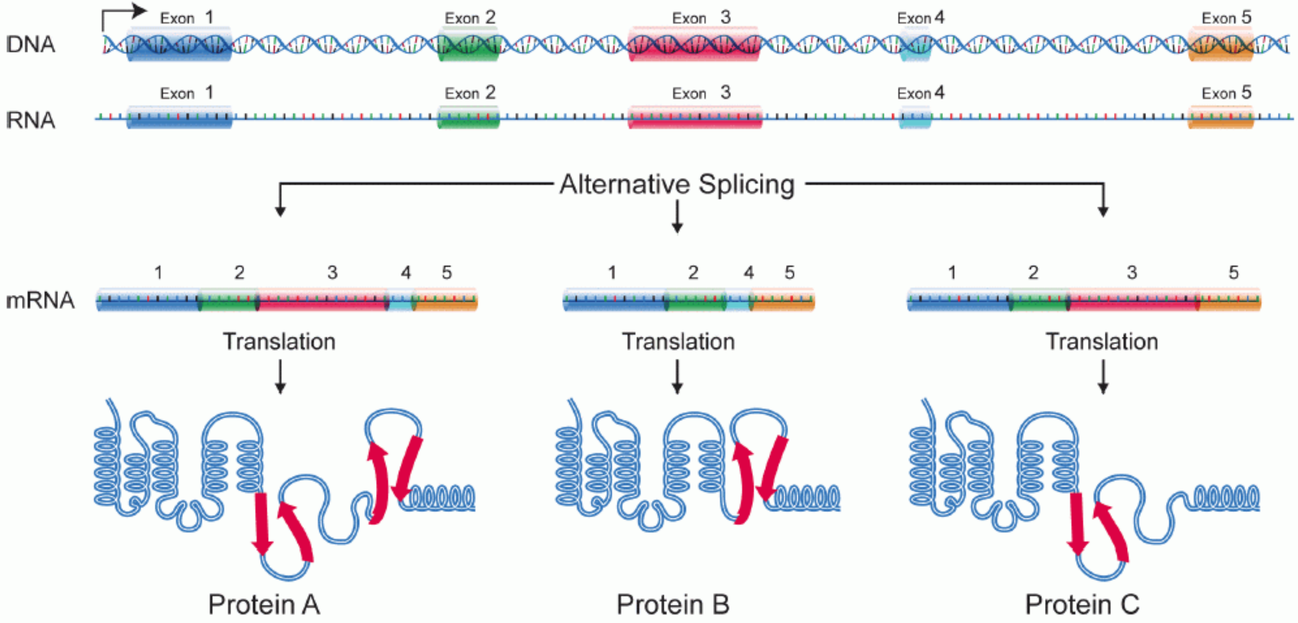


Transcription: DNA -> messenger RNA (mRNA)

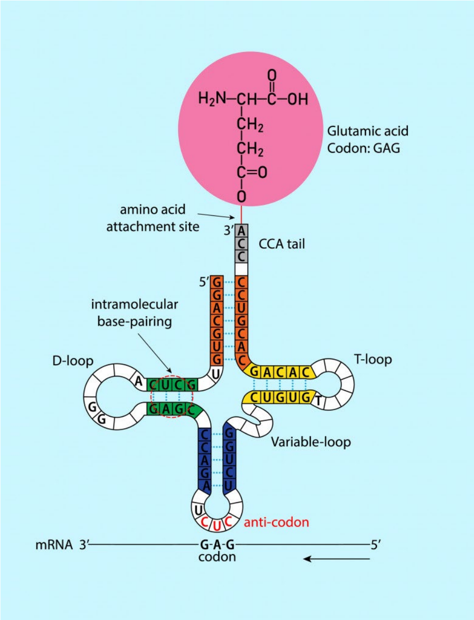


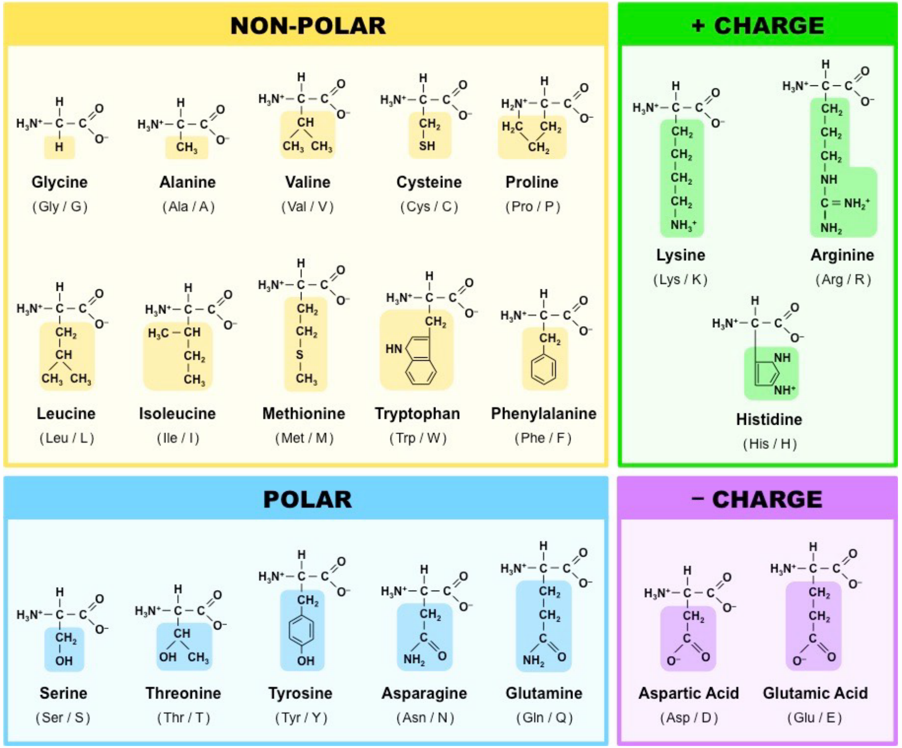


DNA -> messenger RNA (mRNA): Alternative splicing

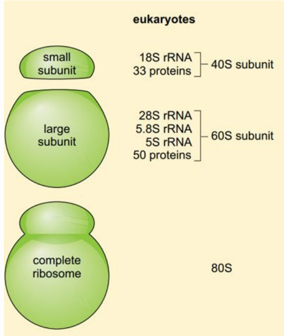


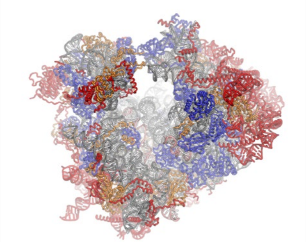
DNA -> transfer RNA (tRNA)

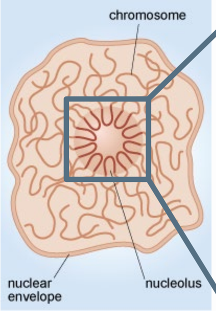




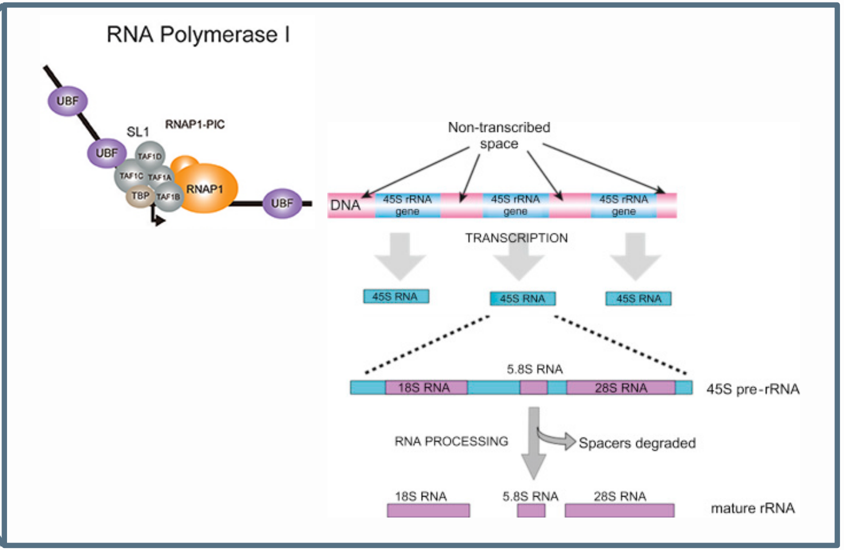
DNA -> ribosomal RNA (rRNA)







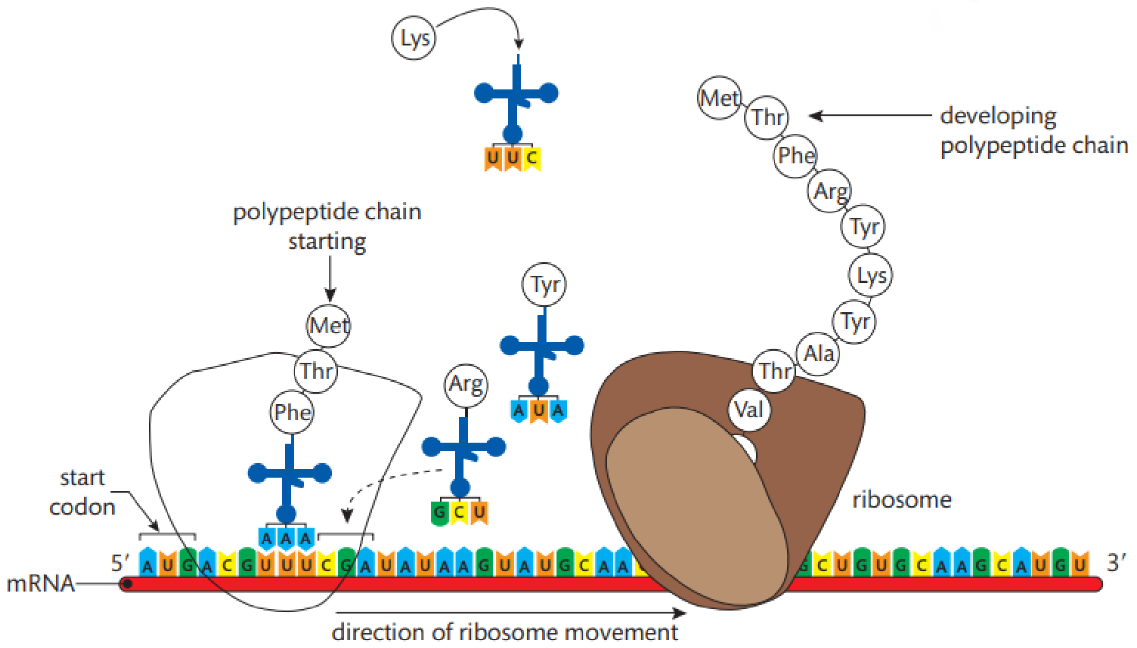
Schematic diagram of the arrangement of chromosomes with respect to the nucleolus.



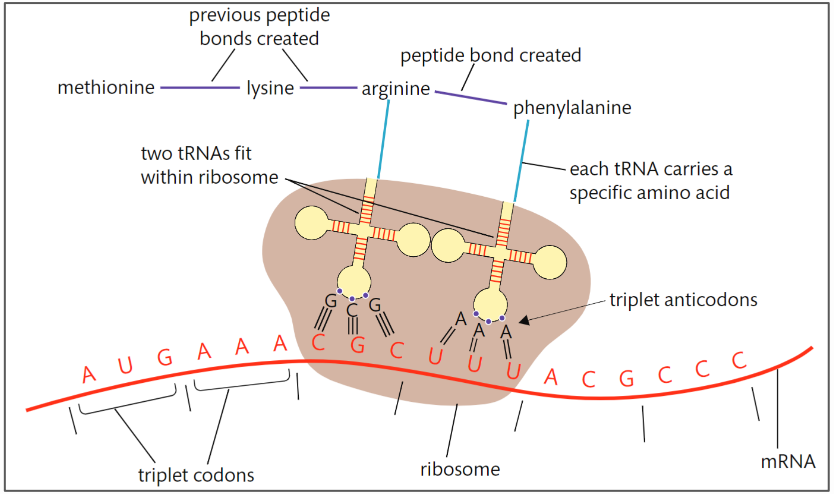
- RNA polymerase I synthesises pre-rRNA from DNA
- Pre-rRNA is spliced to form 18S, 5.8S, and 28S strands
- The two strands bind to ribosomal proteins to form the complete ribosome

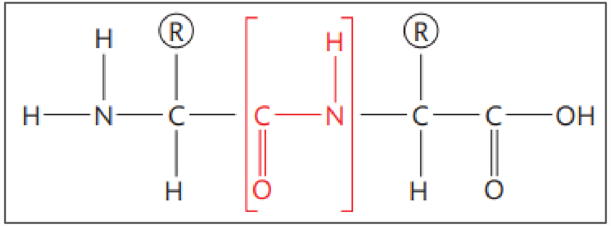
Translation: mRNA -> Protein

- Initiation
- Elongation
- Translocation
- Termination



Peptide bond





How many amino acids could we code for?

FIRST POSITION	SECOND POSITION: U	C	A	G	THIRD POSITION
U	Phenyl alenine	Serine	Tyrosine	Cysteine	U
					C
	Lencine		Stop	Stop	A
			Stop	Tryptophan	G
C	Lencine	Proline	Histidine	Arginine	U
					C
			Glutamine		A
					G
A	Isoleucine	Threonine	Asparagine	Serine	U
					C
			Lysine	Arginine	A
	*Methionine				G
G	Valine	Alanine	Aspartic acid	Glycine	U
					C
			Glutamic acid		A
					G

*And start.

- We could code for 4^3 = 64 amino acids
- Codon degeneracy

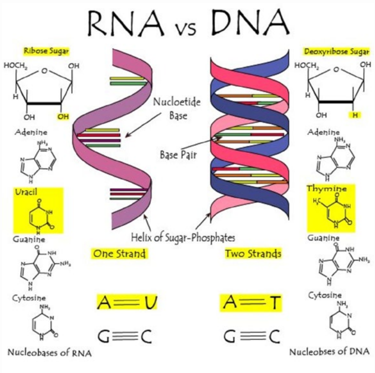
Codon degeneracy makes the genetic code more fault-tolerant for point mutations.

Test

- DNA: TACGGGGCGTGCAAAGGTTCGGGGCCCATT

- mRNA: AUGCCCCGCACGUUUCCAAGCCCCGGGUAA

- Polypeptide: Methionine-proline-arginine-threonine-phenylalanine-proline-serine-proline-glycine-stop



FIRST POSITION	SECOND POSITION: U	C	A	G	THIRD POSITION
U	Phenyl alenine	Serine	Tyrosine	Cysteine	U
U	Phenyl alenine	Serine	Tyrosine	Cysteine	C
U	Lencine	Serine	Stop	Stop	A
U	Lencine	Serine	Stop	Tryptophan	G
C	Lencine	Proline	Histidine	Arginine	U
C	Lencine	Proline	Histidine	Arginine	C
C	Lencine	Proline	Glutamine	Arginine	A
C	Lencine	Proline	Glutamine	Arginine	G
A	Isoleucine	Threonine	Asparagine	Serine	U
A	Isoleucine	Threonine	Asparagine	Serine	C
A	Isoleucine	Threonine	Lysine	Arginine	A
A	*Methionine	Threonine	Lysine	Arginine	G
G	Valine	Alanine	Aspartic acid	Glycine	U
G	Valine	Alanine	Aspartic acid	Glycine	C
G	Valine	Alanine	Glutamic acid	Glycine	A
G	Valine	Alanine	Glutamic acid	Glycine	G

*And start.

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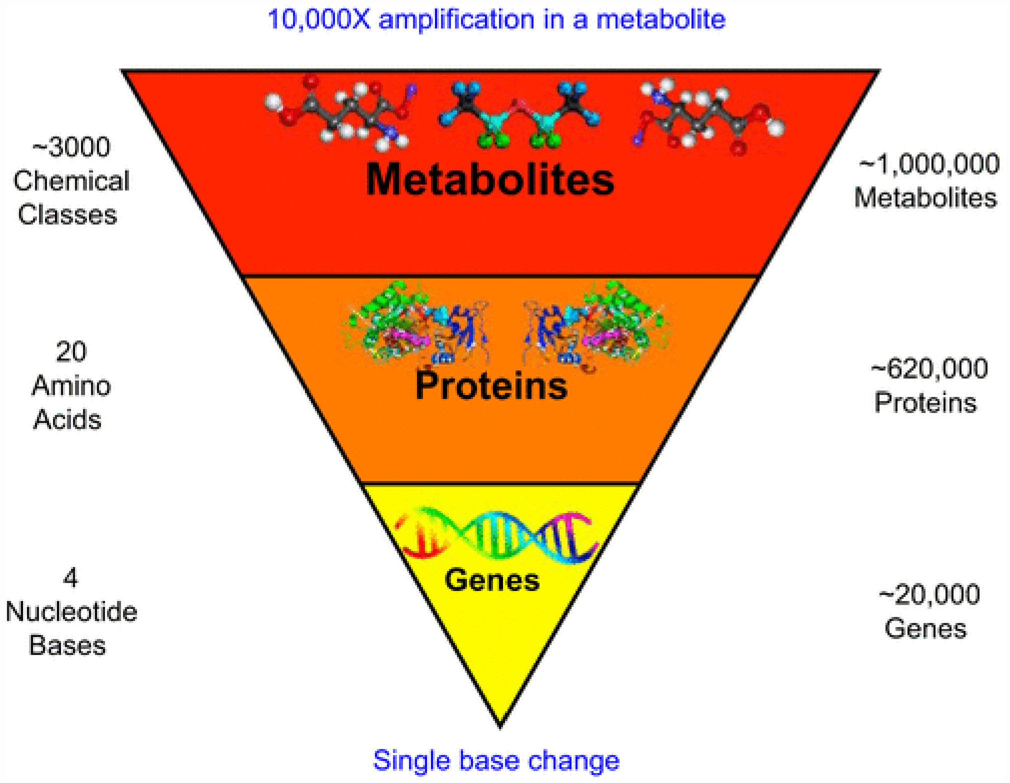
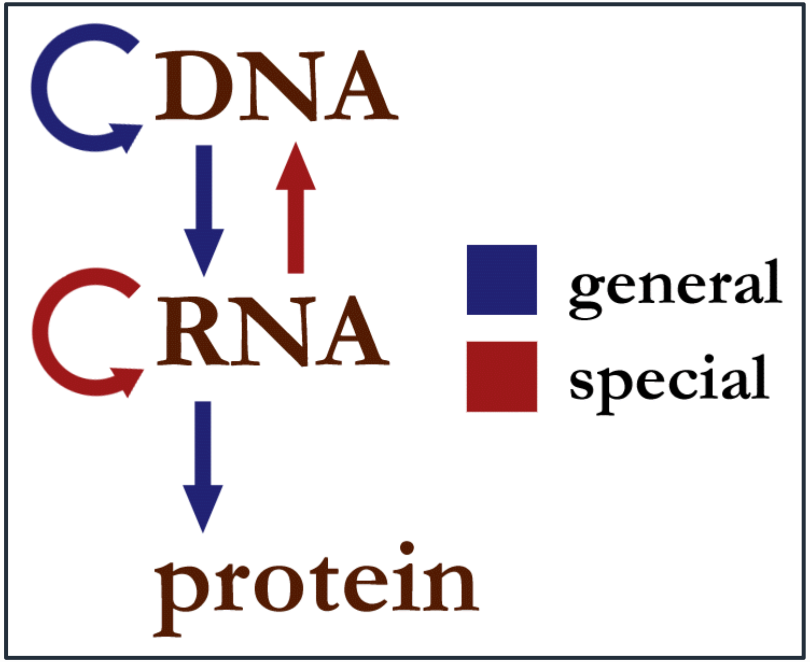
Omics complexity



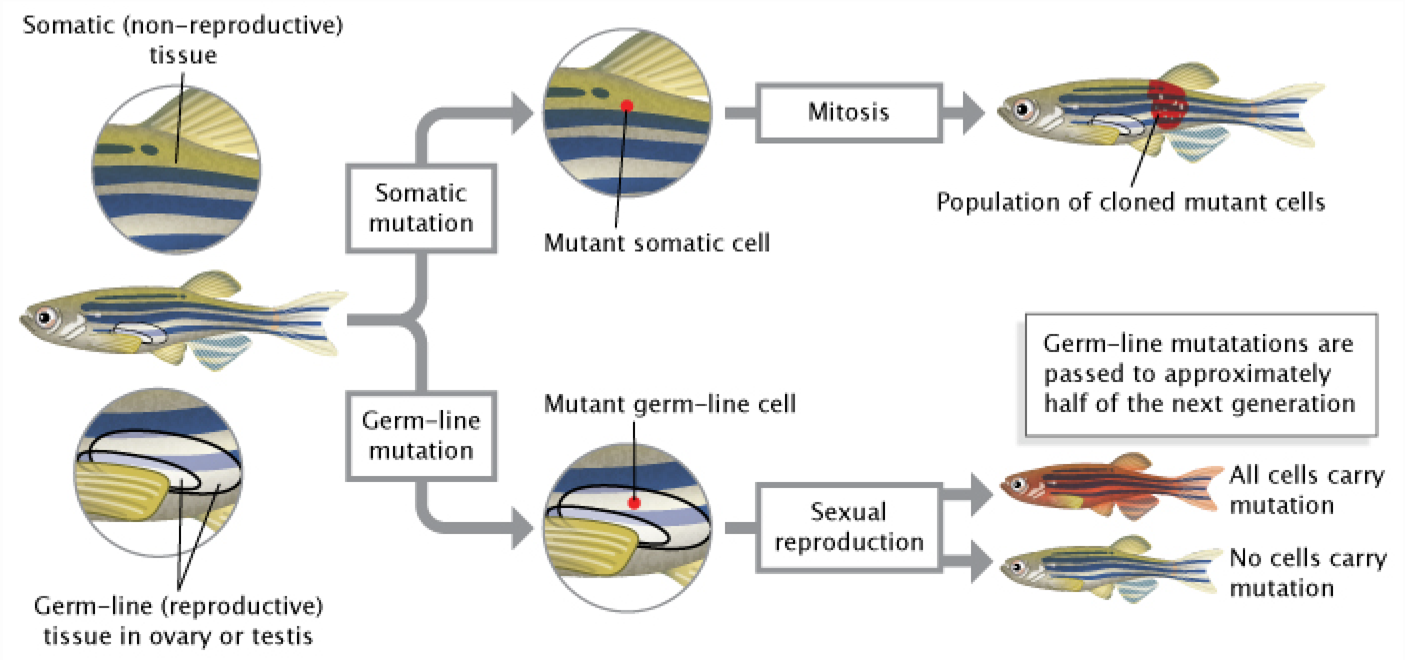
The combinatorial complexity increases dramatically with each additional “ome”.

Exceptions

- Non-coding RNA
- Reverse transcription
- RNA replication



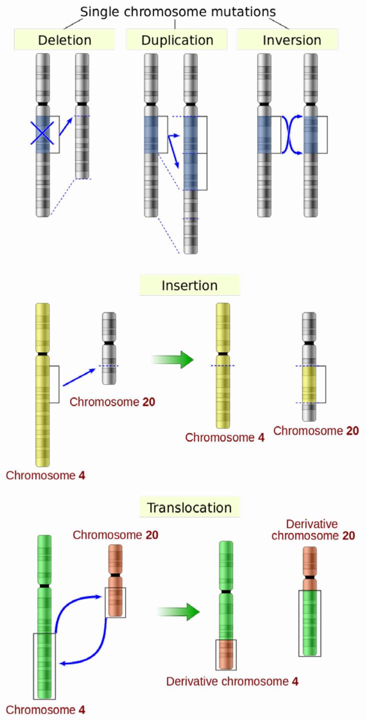
Mutations

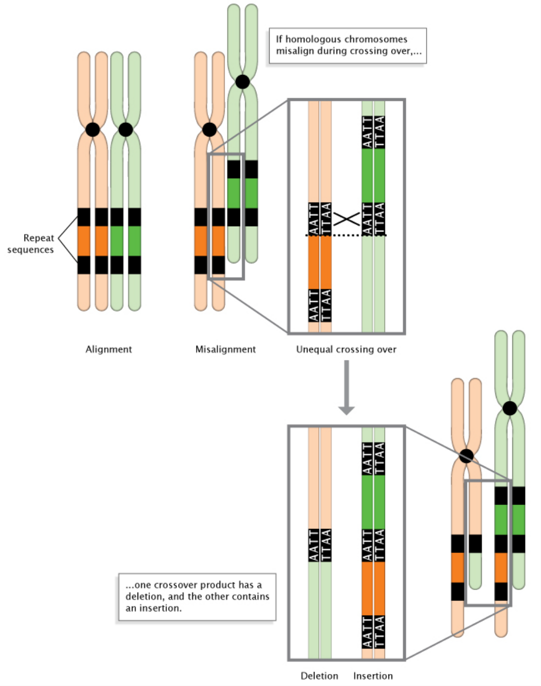


Somatic (non–reproductive) tissue
Somatic mutation
Mutant somatic cell
Mitosis
Population of cloned mutant cells
Germ–line mutation
Mutant germ–line cell
Germ–line (reproductive) tissue in ovary or testis
Sexual reproduction
Germ–line mutations are passed to approximately half of the next generation
All cells carry mutation
No cells carry mutation

Mutations

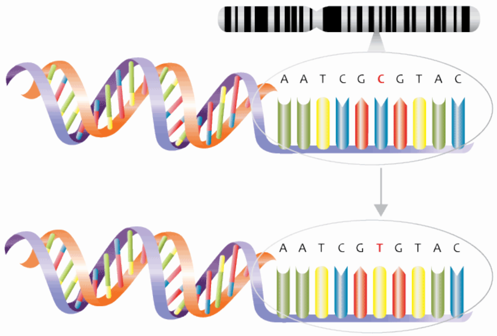
Large-scale mutations





Small-scale mutations

- Insertions
- Deletions
- Point mutations (if more than 1% of the population does not carry the same nucleotide at a specific position in the DNA sequence, then this variation can be classified as a single nucleotide polymorphism, or SNP)

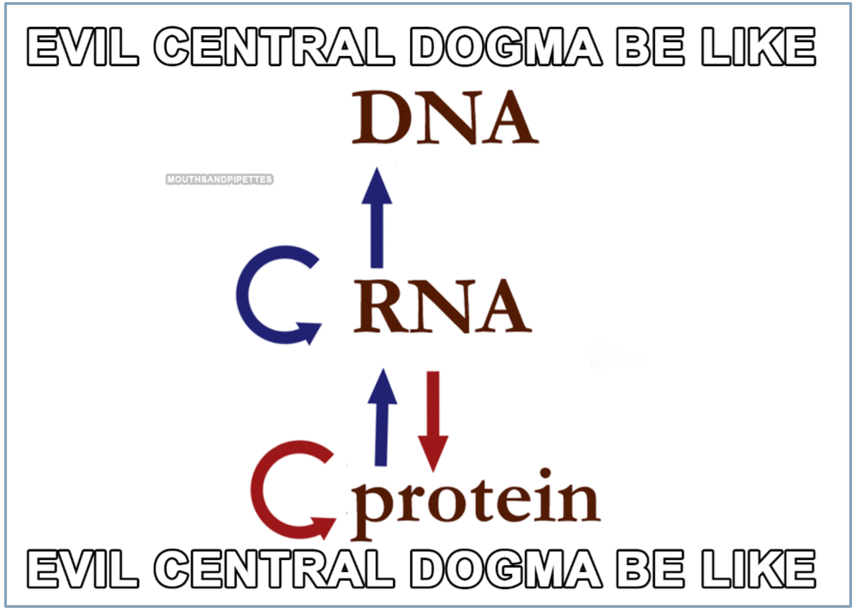


Learning outcomes

- **Biomedical science**
  - Molecules of life I
    - Atoms and periodicity
    - Carbon
    - Water
    - Carbohydrates
    - Lipids
    - Proteins
  - Molecules of life II
    - Nucleic acids
    - DNA and RNA
    - Heredity and genetics
  - Cells
    - Cell theory
    - Ultrastructure
    - Cell cycle
    - Mitosis
    - Meiosis
  - The central dogma I
    - The central dogma
    - Transcription
    - Translation
    - Mutations
  - The central dogma II
    - Gene regulation
    - OMICs Technologies

Thank you for listening!

Email: sonja.tang19@imperial.ac.uk



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Introduction to Biomedical Science - 5th Session: The Central Dogma II

Sonja N. Tang, MSc

(sonja.tang19@imperial.ac.uk)

Learning outcomes

- Biomedical science
  - Molecules of life I
    - Atoms and periodicity
    - Carbon
    - Water
    - Carbohydrates
    - Lipids
    - Proteins
  - Molecules of life II
    - Nucleic acids
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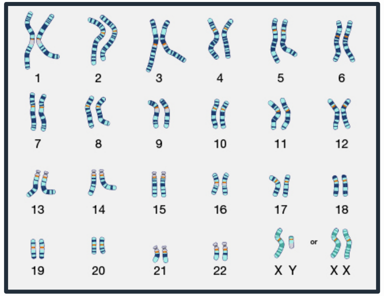
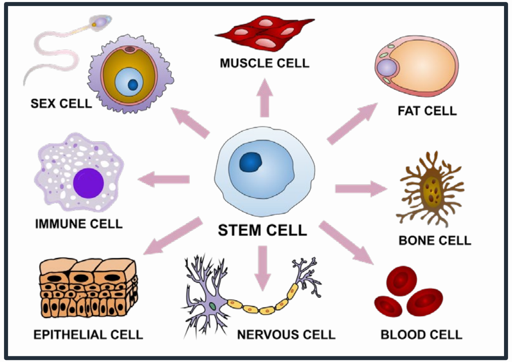
  - Cells
    - Cell theory
    - Ultrastructure
    - Cell cycle
    - Mitosis
    - Meiosis
  - The central dogma I
    - The central dogma
    - Transcription
    - Translation
    - Mutations
  - The central dogma II
    - Gene regulation
    - OMICs Technologies

How can one genome give rise to so many different types of cells?

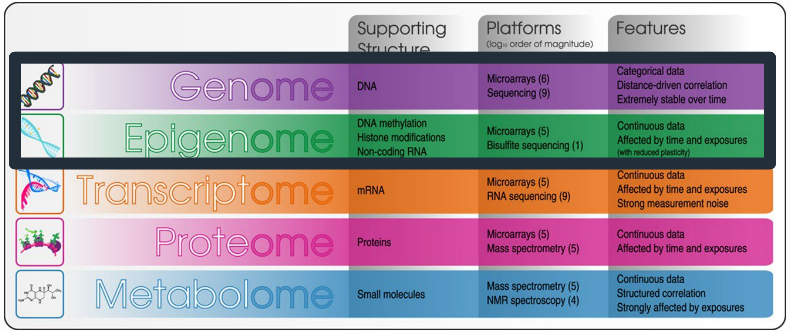




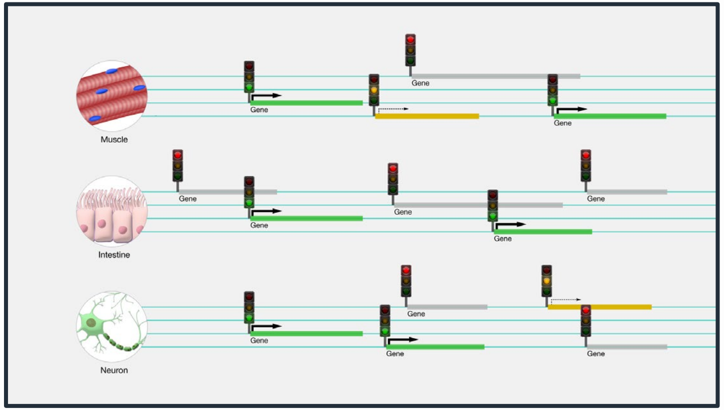
Gene expression is analogous to playing the piano, where the piano keys represent an individual's genome. While the keys on a piano are always the same (genome), which keys you press and at what time determines the song (gene expression). This way, one piano can give rise to infinitely many songs (gene expression profiles).

The **regulation of gene expression (gene regulation)** gives organisms the ability to express specific amounts of required gene products (proteins or RNA) and drive cellular differentiation.

How can one genome give rise to so many different types of cells?



	Supporting Structure	Platforms (log₁₀ order of magnitude)	Features
Genome	DNA	Microarrays (6) Sequencing (9)	Categorical data Distance-driven correlation Extremely stable over time
Epigenome	DNA methylation Histone modifications Non-coding RNA	Microarrays (5) Bisulfite sequencing (1)	Continuous data Affected by time and exposures (with reduced plasticity)
Transcriptome	mRNA	Microarrays (5) RNA sequencing (9)	Continuous data Affected by time and exposures Strong measurement noise
Proteome	Proteins	Microarrays (5) Mass spectrometry (5)	Continuous data Affected by time and exposures
Metabolome	Small molecules	Mass spectrometry (5) NMR spectroscopy (4)	Continuous data Structured correlation Strongly affected by exposures



Gene regulation is the process used to control the timing, location and amount in which genes are expressed without altering the DNA sequence.

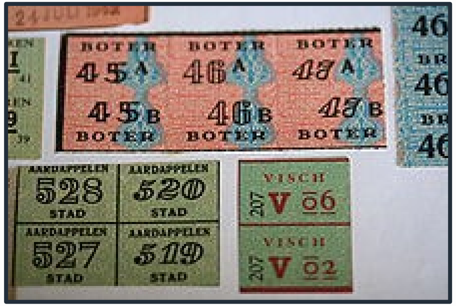
Epigenetic regulation is the stable covalent change to gene expression that is often heritable.

The **regulation of gene expression (gene regulation)** provides the link between nature and nurture.

Examples and early records of epigenetic regulation

Scott and Mark Kelly

Dutch famine of Sept. 1944 to May 1945



Famine and human development: The Dutch hunger winter of 1944-1945.
Z Stein, M Susser, G Saenger, F Marolla - 1975 - psycnet.apa.org
Presents findings from a study of the long-term consequences of undernutrition for 40,000 children conceived and born during the Dutch" hunger winter" which took place near the end of World War II. Data on the effects of intra-uterine exposure to famine on fertility, fetal growth, and mortality, and on mental and physical health in early adult life are explored in addition to the hypothesis that prenatal undernutrition can retard brain growth and impair mental performance.(15 p ref)(PsycINFO Database Record (c) 2016 APA, all rights reserved)
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ELSEVIER
Social Science & Medicine
Volume 119, October 2014, Pages 232-239

Independent and additive association of prenatal famine exposure and intermediary life conditions with adult mortality between age 18–63 years

P. Ekamper [a], F. van Poppel [a, b], A.D. Stein [c], L.H. Lumey [d]

[a] Netherlands Interdisciplinary Demographic Institute NIDI, PO Box 11650, 2502 AR The Hague, Netherlands
[b] Department of Sociology, Utrecht University, PO Box 80140, 3508 TC Utrecht, Netherlands
[c] Rollins School of Public Health, Emory University, 1518 Clifton Road NE, Atlanta, GA 30322, USA
[d] Mailman School of Public Health, Columbia University, 722 West 168 Street, New York, NY 10032, USA

Available online 1 November 2013.

Swedish famine of 1867-69

LONGEVITY DETERMINED BY PATERNAL ANCESTORS' NUTRITION DURING THEIR SLOW GROWTH PERIOD

Lars Olov Bygren[1)], Gunnar Kaati[1)] and Sören Edvinsson[2)]

[1)] Department of Community Medicine and Rehabilitation, Social Medicine, Umeå University, S-90185 Umeå, Sweden.
[2)] Demographic Database, Umeå University, S-90187 Umeå, Sweden.

Received 22-XI-1999

nature COMMUNICATIONS

ARTICLE
There are amendments to this paper
DOI: 10.1038/s41467-018-07617-9 OPEN

Paternal grandfather's access to food predicts all-cause and cancer mortality in grandsons

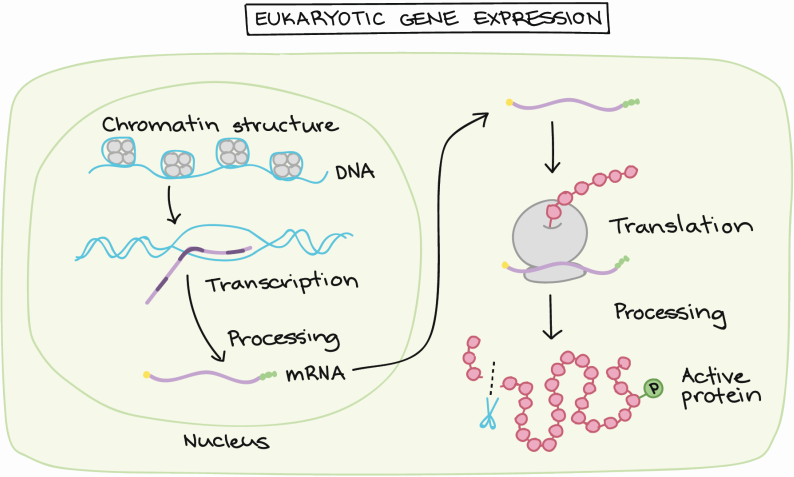
Denny Vågerö [1], Pia R. Pinger [2,3], Vanda Aronsson [1] & Gerard J. van den Berg [4,5]

Learning outcomes – 5th session

1. Gene regulation during:

- **1.1 Transcription**
- **1.2 mRNA processing**
- **1.3 Translation**
- **1.4 Post-translational modifications**

2. OMICs technologies



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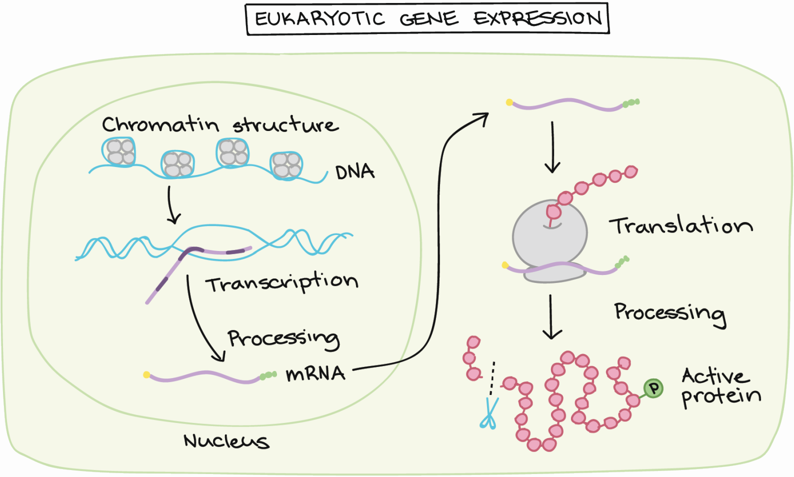

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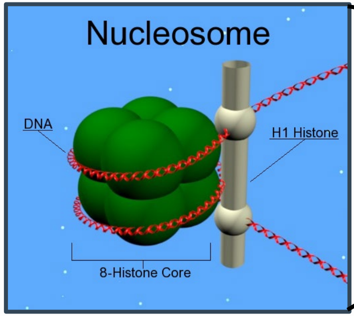
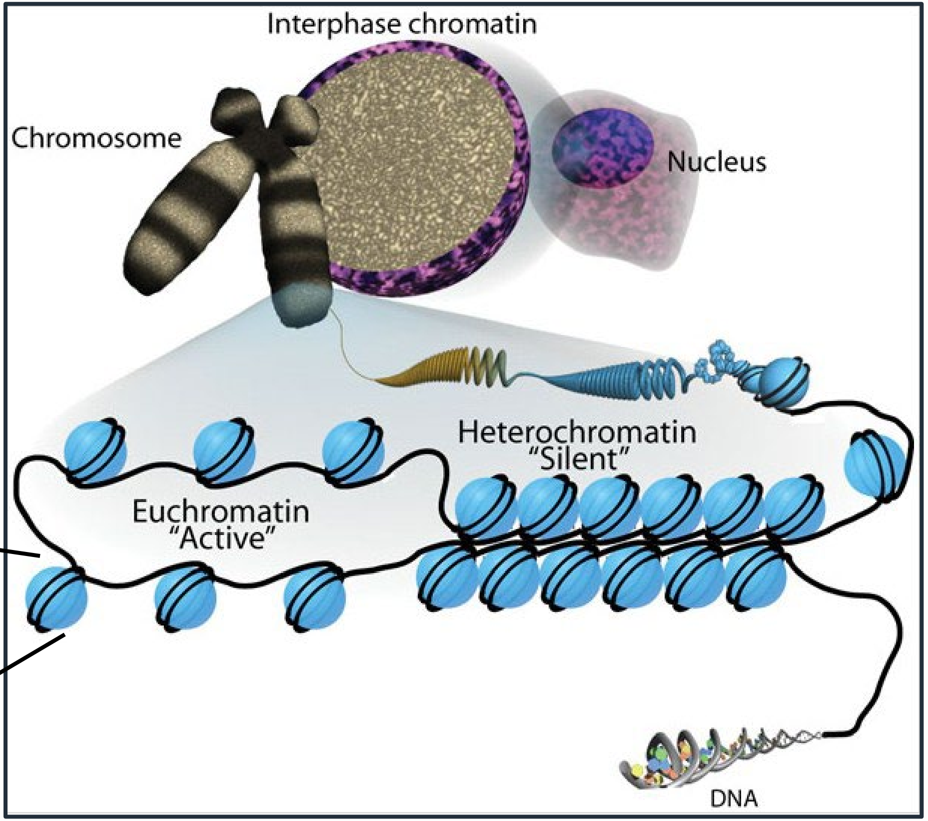
Regulation of the chromatin state

- Chromatin is made up of DNA and proteins, of which histones are the most important.
- Levels of organization:
  1. Euchromatin
  2. Heterochromatin (facultative to constitutive)
  3. Metaphase chromosome

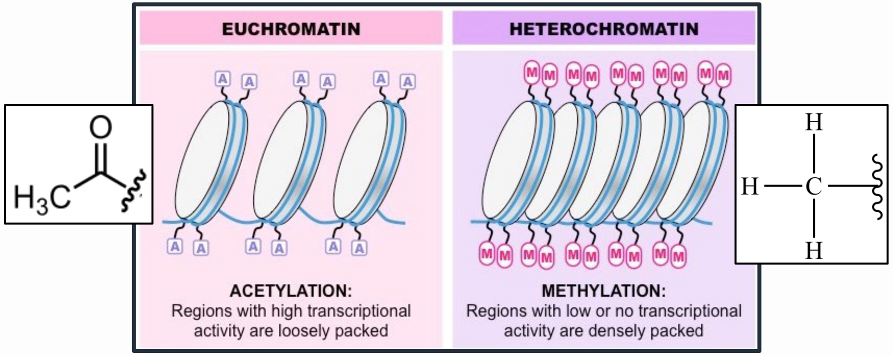


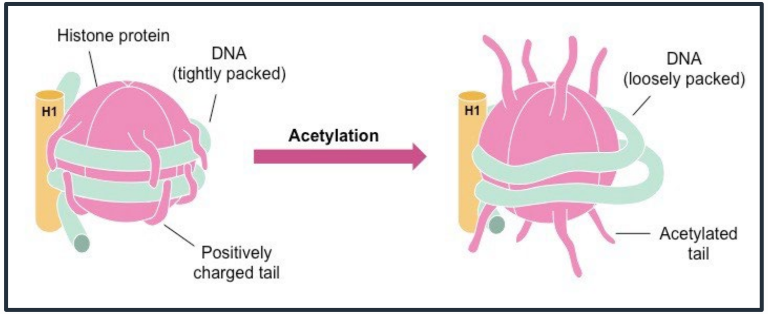


Regulation of the chromatin state

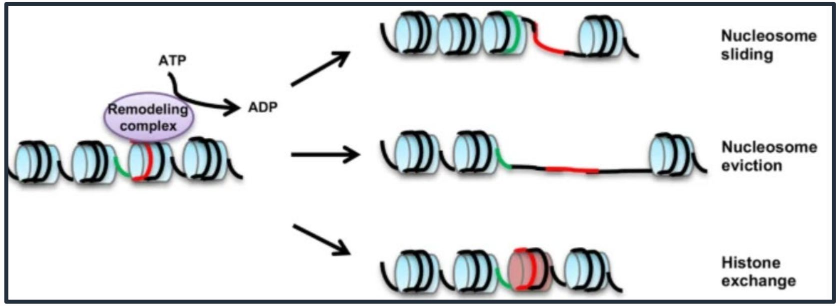
The chromatin state can be regulated through:

1. Covalent histone modifications



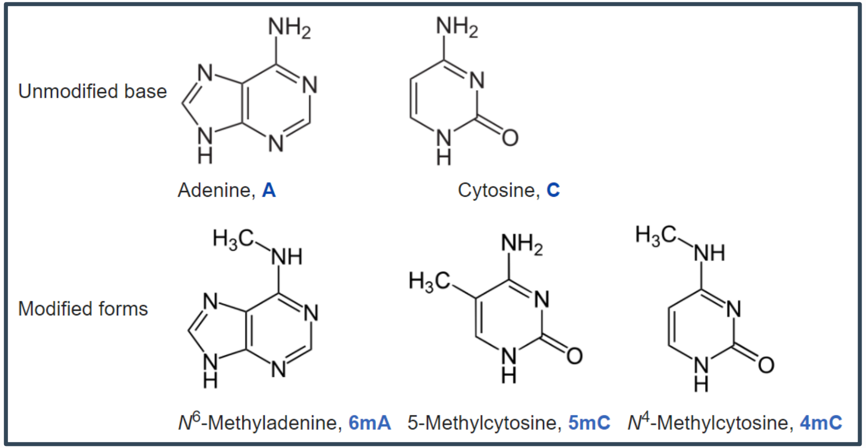


2. ATP-dependent chromatin remodelling



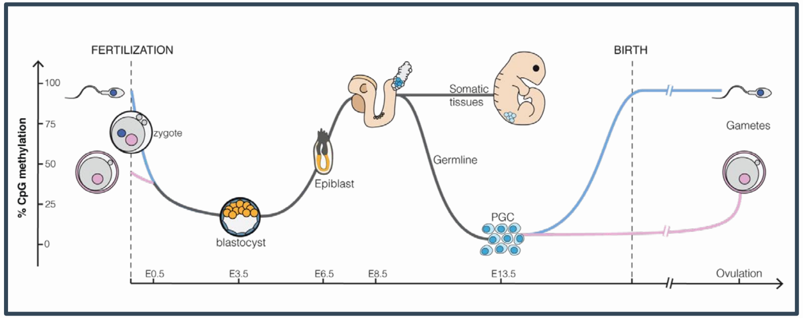
DNA methylation

- Process by which methyl groups (CH_3) are added to the DNA molecule.
- Not to be confused with histone methylation.

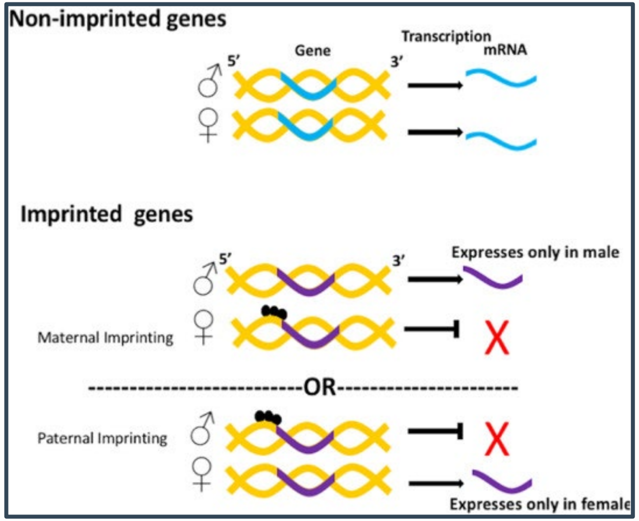


DNA methylation – functions and diseases

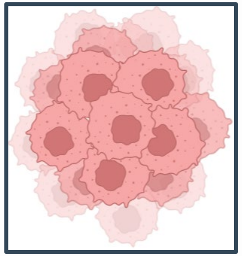
- Embryonic development and aging



- Genomic imprinting: process by which specific genes from only one parent are expressed (e.g. X inactivation).

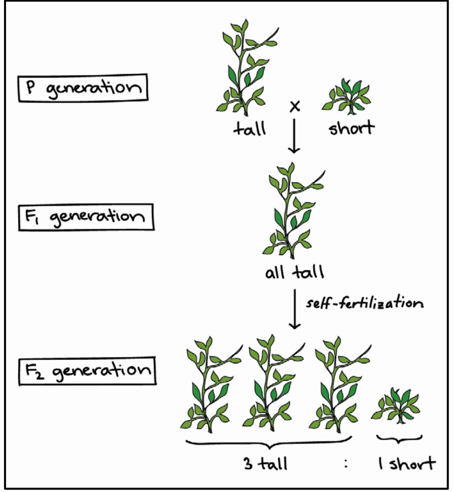


- Cancer and atherosclerosis



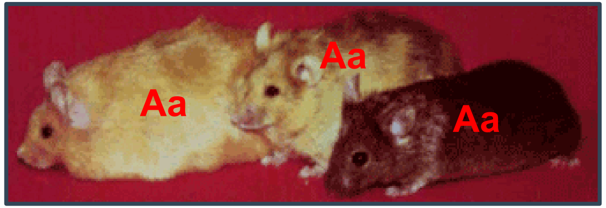
Example of heritable epigenetic regulation

Monohybrid crosses



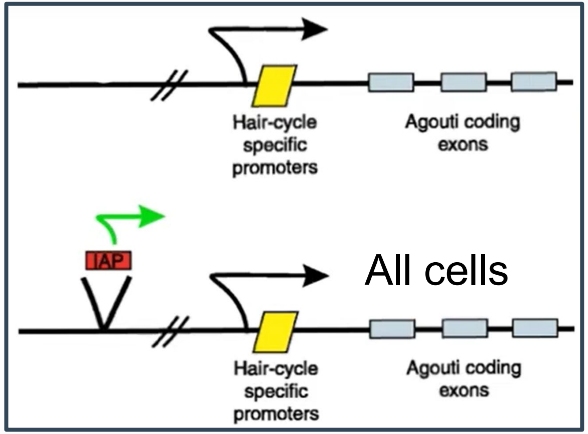
Punnett grid
of F_2 (second filial generation)

	A	a
A	AA	Aa
a	Aa	aa



Agouti mice

- AA, Aa -> yellow fur
- aa -> brown fur



- IAP insertion -> obesity, diabetes, cancer

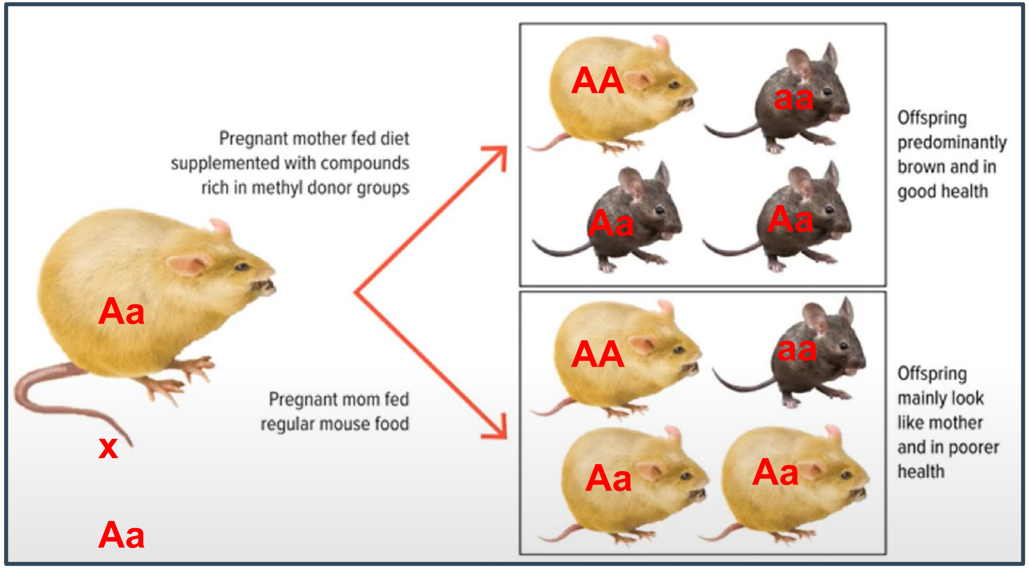
Example of heritable epigenetic regulation

Punnett grid
of F_2 (second filial generation)

	A	a
A	AA	Aa
a	Aa	aa

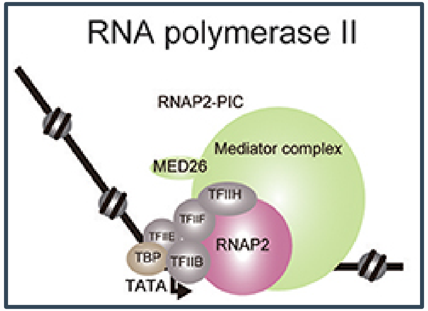
Agouti mice

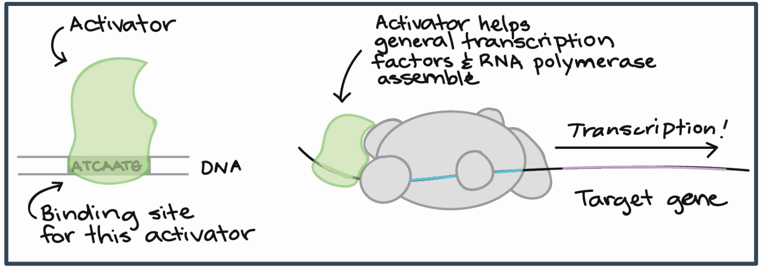
- Agouti gene expression is correlated with yellow fur, obesity, diabetes, cancer
- CpG methylation ↑ = Agouti expression ↓

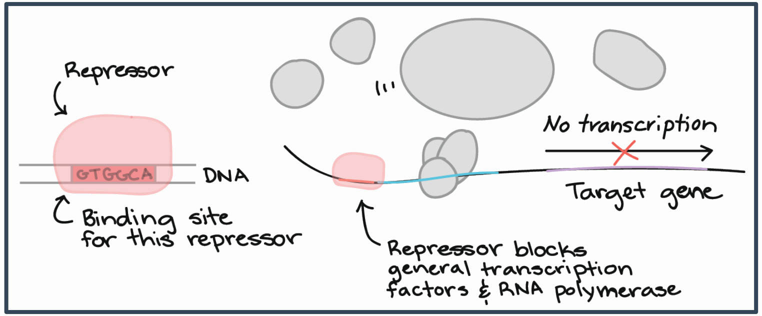


Transcription factors

- **Basal transcription** factors are proteins involved helping RNA polymerase attach to the promoter and in controlling the rate of transcription by binding to specific DNA sequences.
- **Other transcription factors** can turn genes “on” or “off” by binding to nearby DNA.
- **Regulation mechanisms**:
    1. Activators bind to enhancer regions
    2. Repressors bind to silencer regions
    3. Acetylate or deacetylate histones

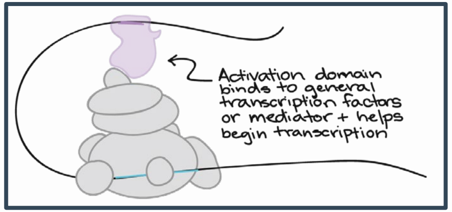


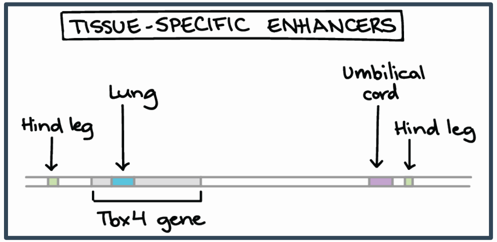




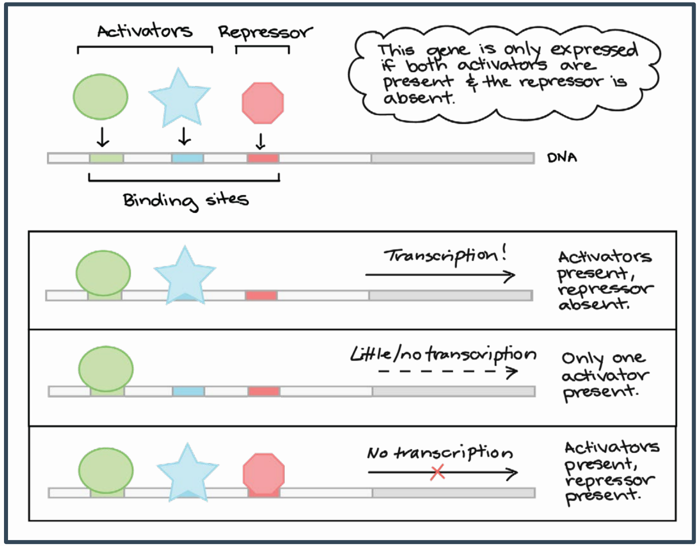
Transcription factors exert combinatorial control

- **Enhancer and silencer regions** can be close to-, or far away from the promoter of a gene.
- A gene may have **several associated enhancer and silencer regions** that can bind specific transcription factors made in different cell types.





- **Combinatorial regulation** of gene expression through transcription factors is analogous to logic gates in computing.



1. Gene regulation during:

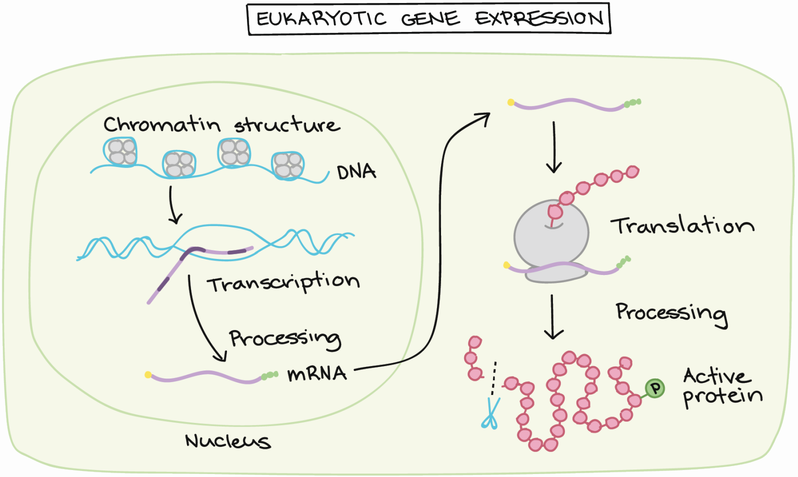
1.1 Transcription

1.2 mRNA processing

1.3 Translation

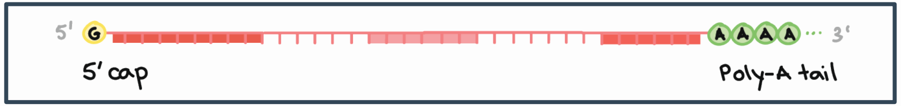
1.4 Post-translational modifications

2. OMICs technologies

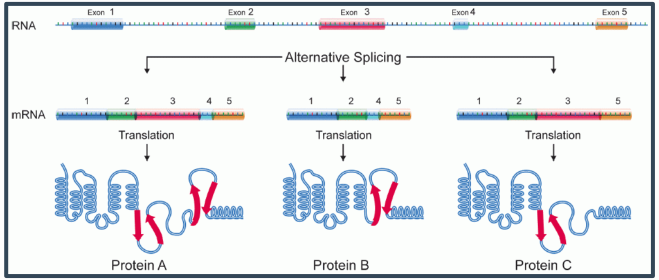


Regulation of mRNA transcripts

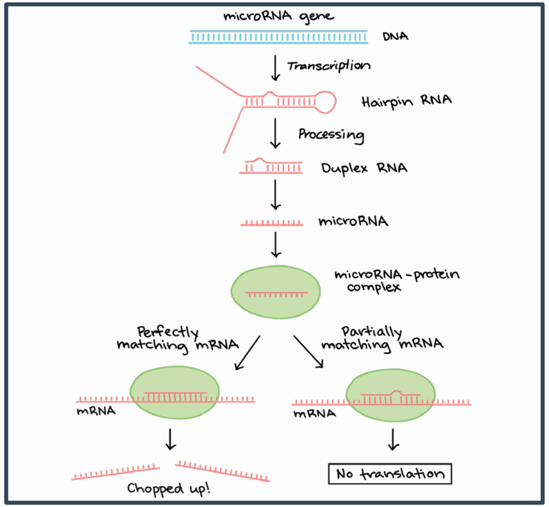
- **Capping**
- **Polyadenylation**



- **Alternative splicing** regulatory proteins



- **microRNA** (miRNA): single-stranded non-coding RNA molecules



Learning outcomes – 5th session

1. Gene regulation during:

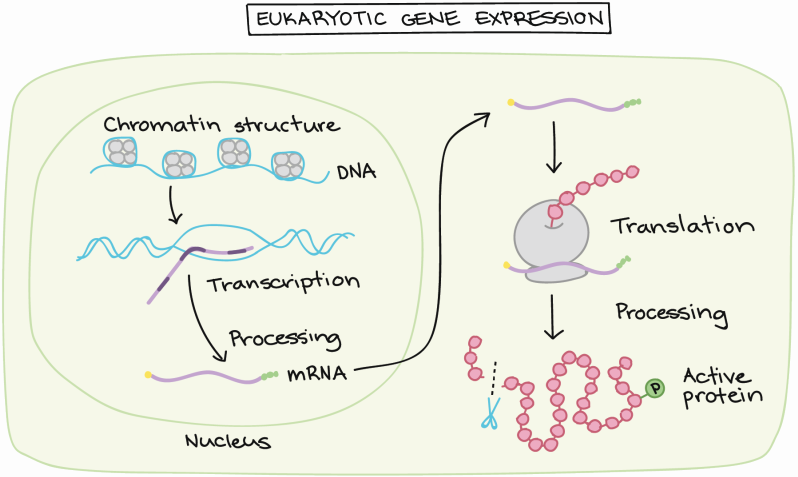
1.1 Transcription

1.2 mRNA processing

1.3 Translation

1.4 Post-translational modifications

2. OMICs technologies



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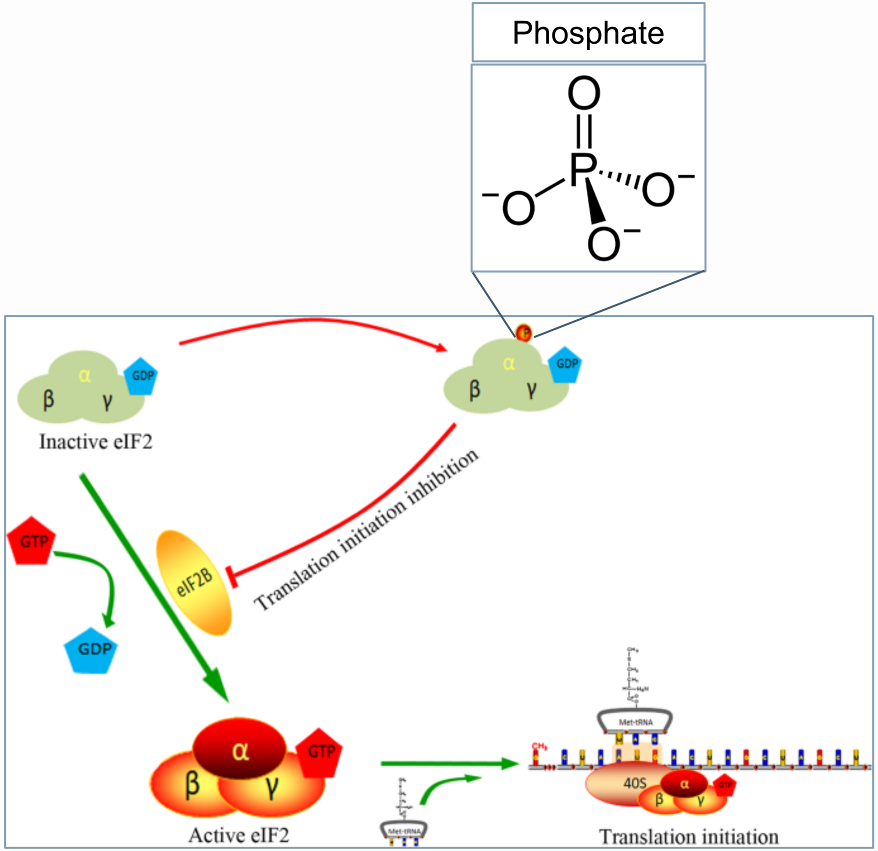
Regulation of ribosome activity

Eukaryotic Initiation Factor 2 (eIF2) is required for translation initiation. A variety of stressors and signals can phosphorylate (add a phosphate group) on the alpha subunit to block eIF2 from initiating translation. Here's how it works:

1. eIF2-GDP is converted to eIF2-GTP by eIF2B.
2. eIF2-GTP can initiate translation.
3. eIF-2-GDP + alpha-subunit-phosphorylation = blocked translation as it cannot be converted to eIF2-GTP.



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1. Gene regulation during:

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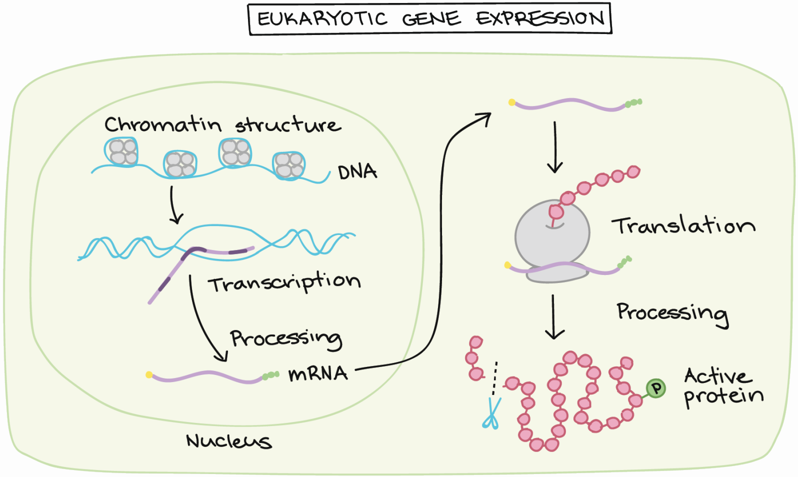

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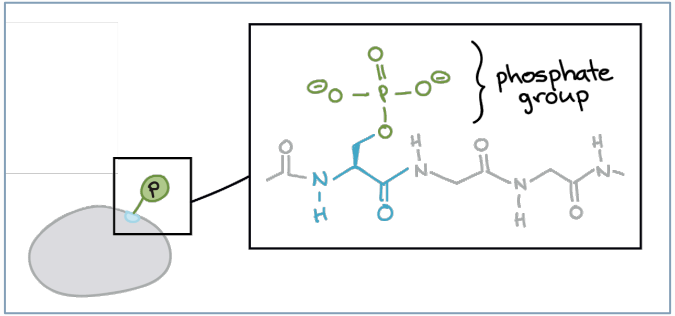
Regulation of protein modifications

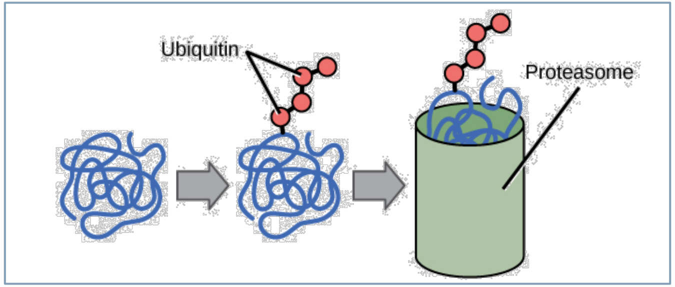
Reversible:

- Phosphorylation
- Acetylation
- Glycosylation



Irreversible:

- Proteolysis – e.g. ubiquitination



Learning outcomes – 5th session

1. Gene regulation during:

   1.1 Transcription

   1.2 mRNA processing

   1.3 Translation

   1.4 Post-translational modifications

2. OMICs technologies

DNA profiling

Tandem repeats: A type of copy number variation where two or more DNA base pairs are repeated in sequence.

Types:

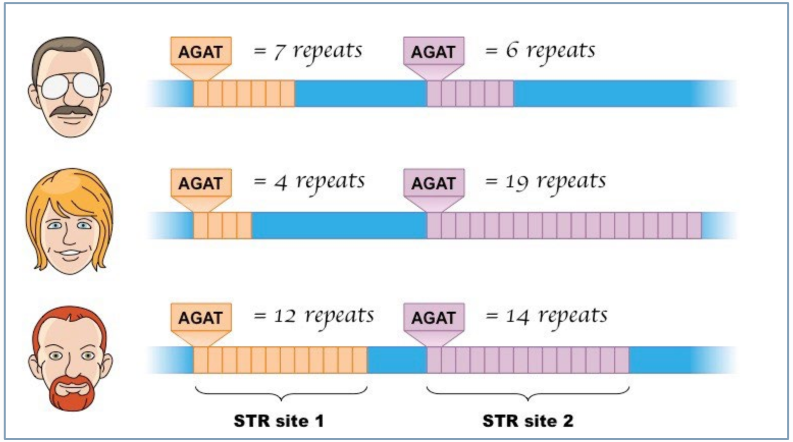
Microsatellites/short tandem repeats (STR) are repeating DNA motifs fewer than 10 nucleotides long. Types:

- Dinucleotide repeat: AGAGAGAG...
- Trinucleotide repeat: AGCAGCAGC...

Minisatellites:

- Repeating DNA motif 10 – 60 nucleotides long.

DNA profiling



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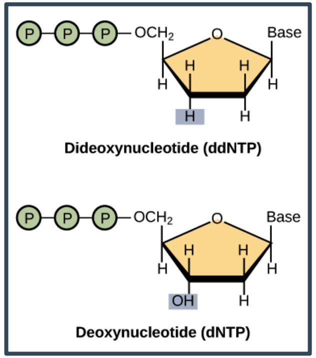
DNA sequencing – determining sequences

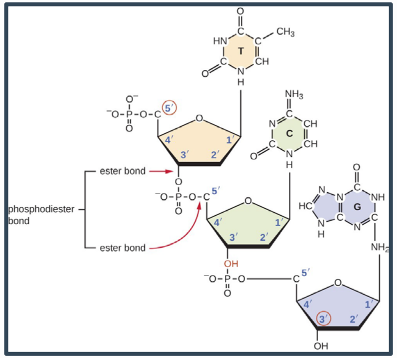
Sanger sequencing:

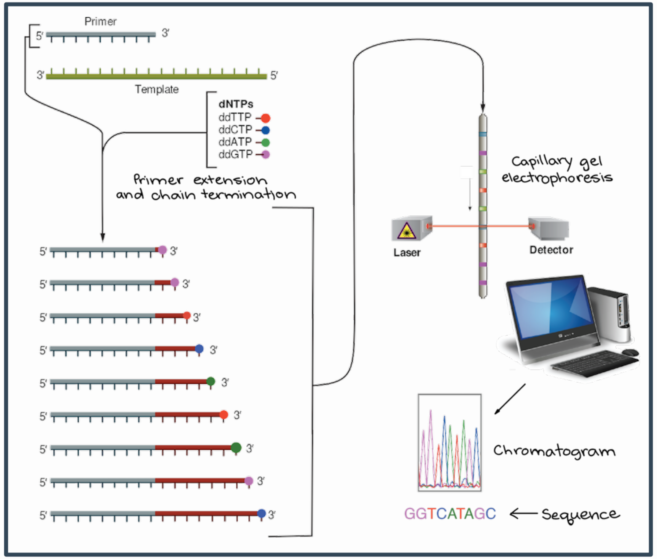
- Makes many copies of a target DNA region using:
  - DNA template to be sequenced
  - DNA polymerase
  - Primer – a piece of single-stranded DNA to start the reaction (18-24 bases)
  - DNA nucleotides: dATP, dTTP, dCTP, dGTP
  - Dyed chain-terminating nucleotides: ddATP, ddTTP, ddCTP, ddGTP

Next-generation sequencing:

- Short-read sequencing
- Long-read sequencing







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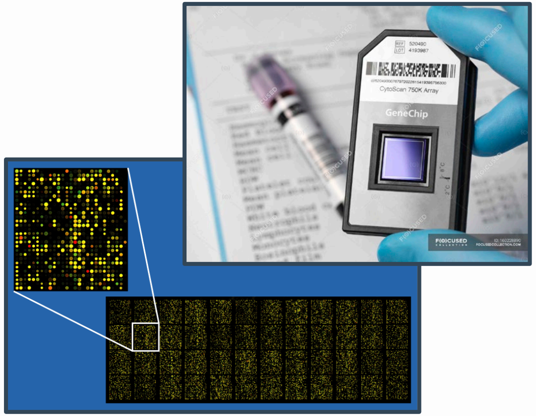
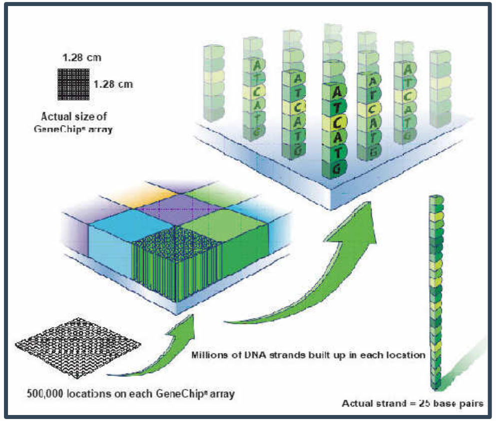
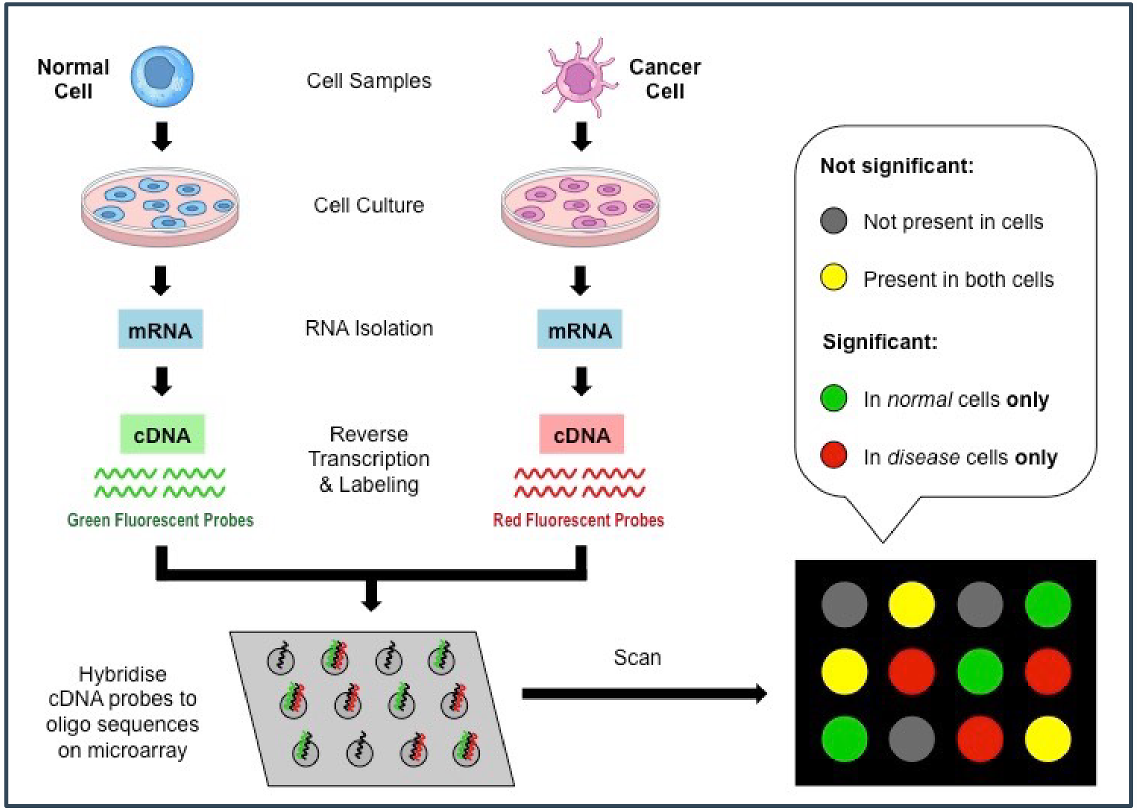
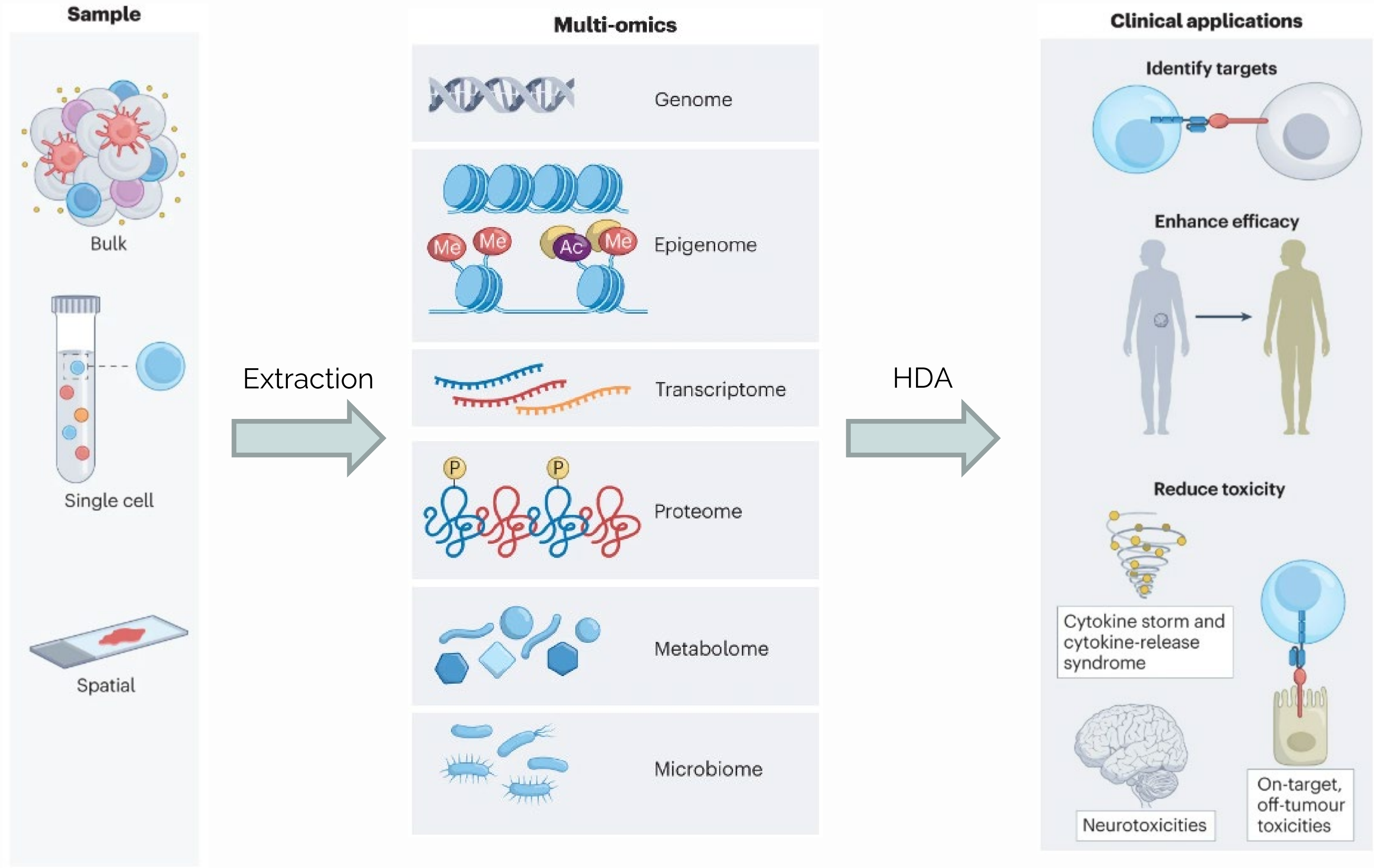
DNA microarrays – detecting gene expression








Sample
Bulk
Single cell
Spatial
Extraction
Multi-omics
Genome
Me
Me
Ac
Me
Epigenome
Transcriptome
P
P
Proteome
Metabolome
Microbiome
HDA
Clinical applications
Identify targets
Enhance efficacy
Reduce toxicity
Cytokine storm and cytokine-release syndrome
Neurotoxicities
On-target, off-tumour toxicities

"The Most Complex Language in the World" by Kurzgesagt – In a Nutshell

Learning outcomes

- **Biomedical science**
  - Molecules of life I
    - Atoms and periodicity
    - Carbon
    - Water
    - Carbohydrates
    - Lipids
    - Proteins
  - Molecules of life II
    - Nucleic acids
    - DNA and RNA
    - Heredity and genetics
  - Cells
    - Cell theory
    - Ultrastructure
    - Cell cycle
    - Mitosis
    - Meiosis
  - The central dogma I
    - The central dogma
    - Transcription
    - Translation
    - Mutations
  - The central dogma II
    - Gene regulation
    - OMICs Technologies

Thank you for listening!

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