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TOPIC 1. CELL BIOLOGY
1.1. Introduction to cells

IB BIOLOGY I

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CELL THEORY

- The **CELL THEORY** was formulated in the 19th century; the updated version is:
  1. **Living organisms are composed of cells**
  2. **Cells are the smallest unit of life**

     The cell is the structural & functional UNIT of all living things.
  1. **Cells come from pre-existing cells**

- Stated in this way Cell Theory might be attributed to Schleiden and Schwann (1838).
- Robert Hooke first coined the term 'cell' after observing the structure of cork in 1655.
- The first observation of living cells was by Anton van Leeuwenhoek in 1674.

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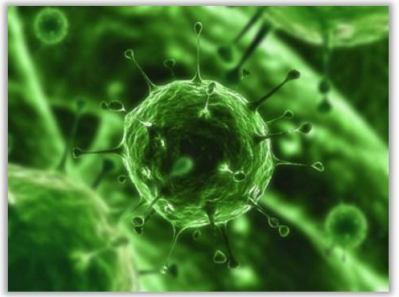
WHAT ABOUT VIRUSES?

- Cells contain hereditary information which is passed on during cell division.
- All cells are basically the same in chemical composition.
- All energy flow (metabolism & biochemistry) of life occurs within cells.

- A VIRUS is **NOT** made of cells.
- It is a tiny structure about a tenth of the size of a prokaryotic cell.
- It has no membrane or cytoplasm.
- It cannot metabolize.
- It is a PARASITE.
- It consists of a NUCLEIC ACID (either DNA or RNA) covered by a PROTEIN coat.
- The protein coat recognizes structures on the surface of cells, both prokaryote and eukaryote; attaches, injects its nucleic acid, takes over the cell and produces more viruses.



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EVIDENCE FOR THE CELL THEORY

Living organisms are composed of cells

- **EVIDENCE:** observations using microscopes

Cells are the smallest unit of life

- **EVIDENCE:** discovery of viruses, isolated organelles in the lab survive a short time

Cells come from pre-existing cells

- **EVIDENCE:** spontaneous generation disproved by experiments, discovery of spores, observation of mitosis

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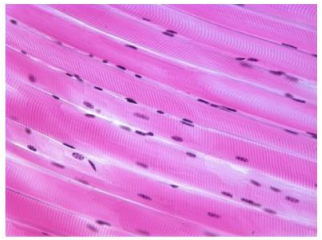
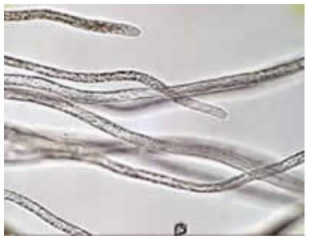
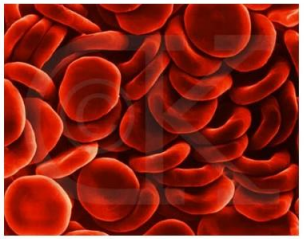
EXCEPTIONS TO THE CELL THEORY

- Long thin MULTINUCLEATE cells are found in **skeletal muscle** *and* **fungal hyphae**.
- **Bone cells** have a matrix of extracellular material around them.
- **Erythrocytes** (red blood cells) do NOT have nuclei.
- Some biologists consider unicellular organisms to be *acellular*, because they are larger than a typical cell, and carry out ALL life functions-- example **Amoeba**

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FUNCTIONS OF LIFE

- *Unicellular* organisms must carry out ALL the **FUNCTIONS OF LIFE:**

metabolism
nutrition
response
reproduction
homeostasis
growth

Tip: MN R^2 GH

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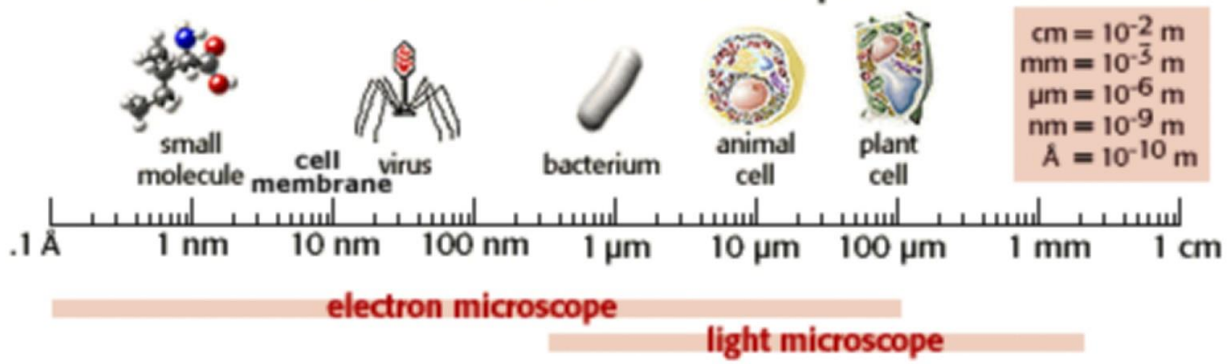
RELATIVE SIZES

			average size	
C	CELLS	100	100 µm	micrometer
O	ORGANELLES	10	10 µm	micrometer
B	BACTERIA	1	1 µm	micrometer
V	VIRUS	100	100 nm	nanometer
M	CELL MEMBRANE	10	10 nm	nanometer
M	MOLECULE	1	1 nm	nanometer

1000 µm = 1 mm

1000 nm = 1 µm

Relative sizes of cells and their components



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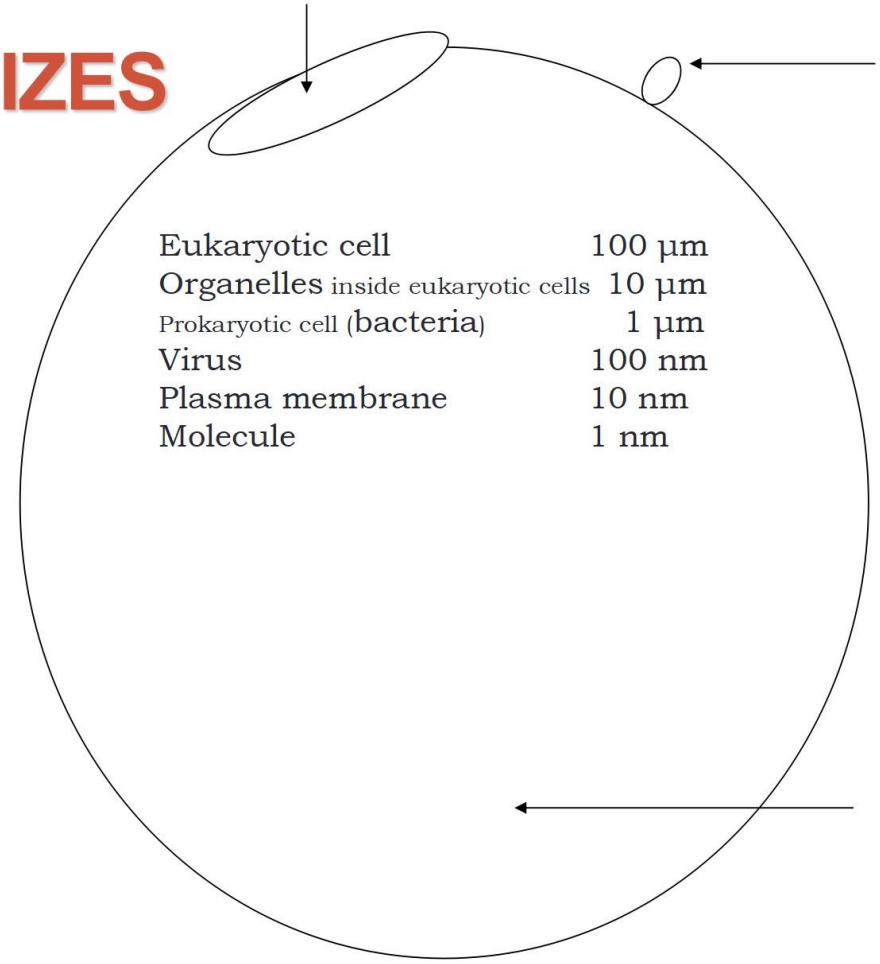
RELATIVE SIZES



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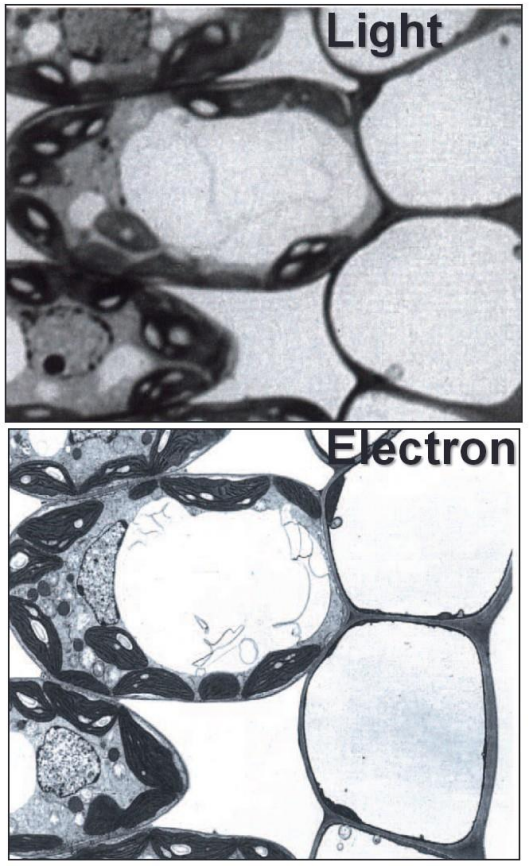
MICROSCOPES

Resolution: refers to the ability to distinguish two objects as separate entities.

Magnification: refers to the ability to increase the size of a viewed object.



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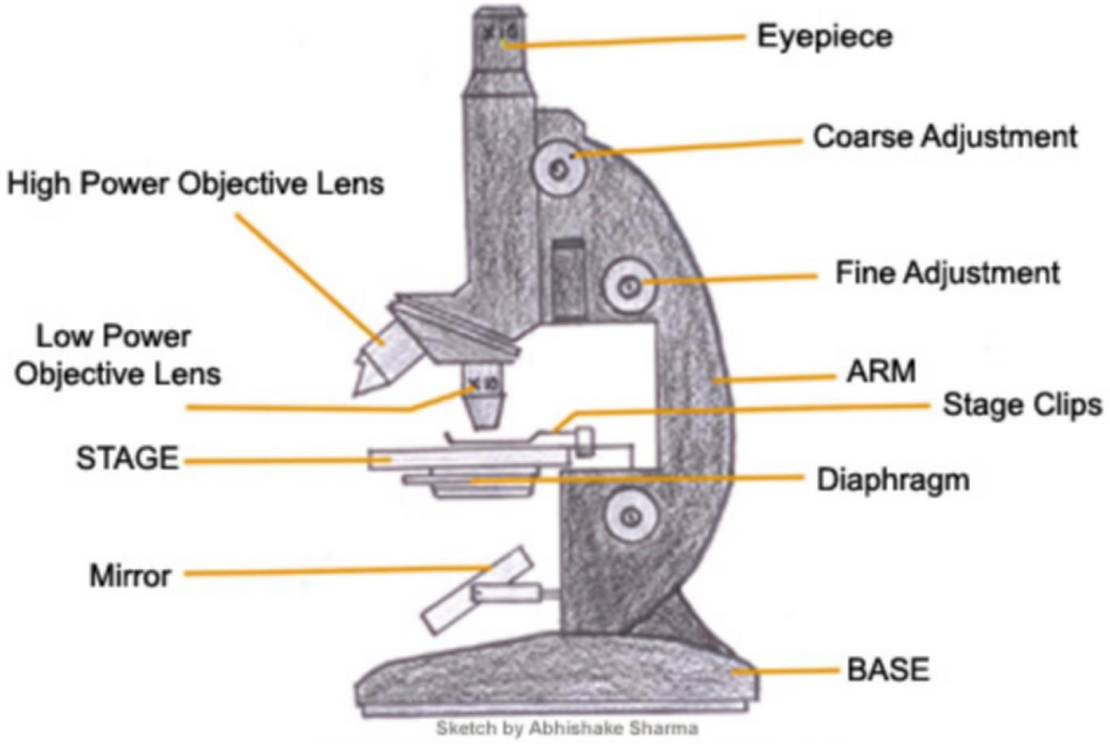
MICROSCOPE



Labeled Microscope Diagram

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MICROSCOPES

Light

- Display color instead of monochrome (black and white) images.
- Provide a large field of view.
- Facilitate preparation of sample material.
- Allow for the examination of living material and the observation of movement.
- Cheap in comparison to electron microscopes.

Electron

- Provide images of higher *resolution (200x greater)* and *magnification* than light microscopes.
- May provide a three dimensional view.
- Difficult and elaborate preparation of sample material (requires vacuum).
- Only allows examination of fixed non-living material.
- Expensive compared to light microscope.

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MAGNIFICATION

$$\text{Magnification} = \frac{\text{IMAGE size}}{\text{ACTUAL size}}$$

- **Magnification** usually a large number with many zeros (x1000)
- **Image** usually in cm or mm, or a scale bar must be converted to μm or nm

- **Actual** make sure you label with correct units, either μm or nm

Note: In micrographs most measurements are expressed in micrometers (μm).

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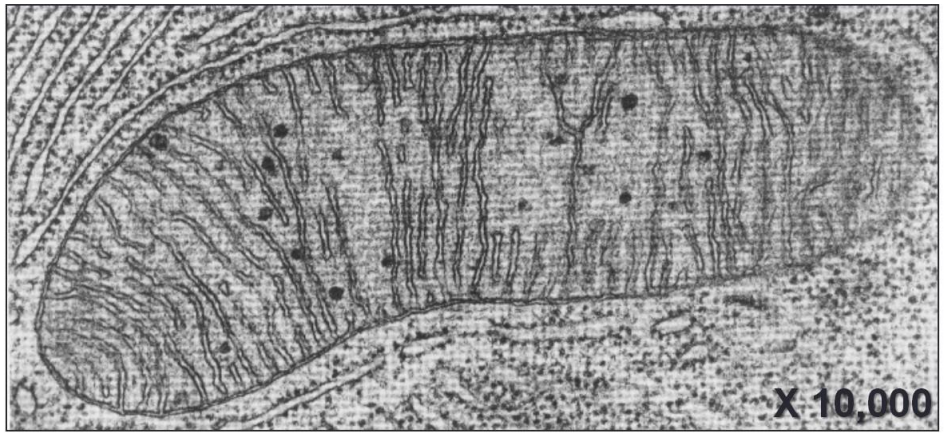

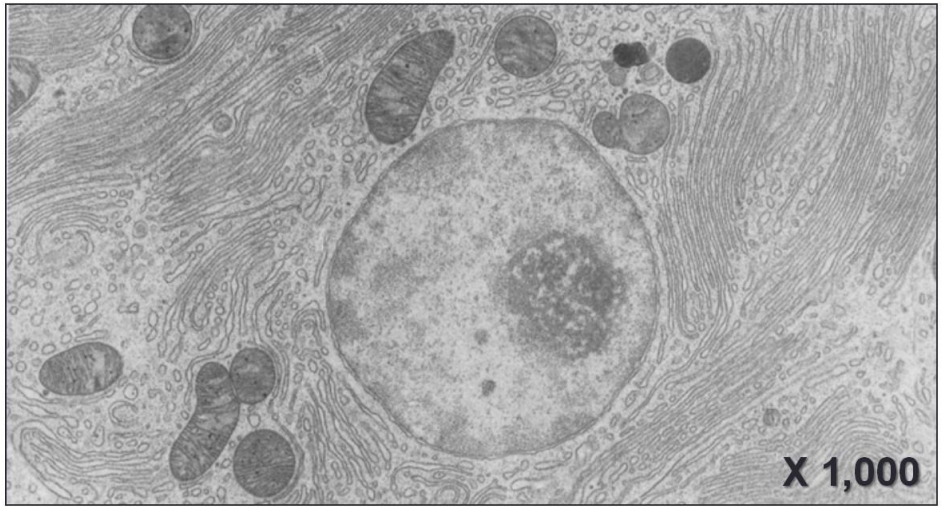

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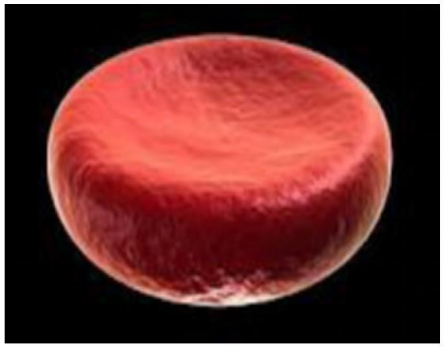
EXAMPLE

- **Size of the cell**
  - Use a ruler to measure the diameter
  - Use a ruler to measure the length of the scale bar
  - Use the ratio of these two values to work out the actual length of the cell

$$\frac{\text{2 µm}}{\text{Length of scale bar}} = \frac{\text{actual size of cell}}{\text{image size}}$$



- **Magnification of image**
  - Use the formula

    magnification = image size / actual size

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SURFACE AREA TO VOLUME RATIO

Cells are very small and cannot grow to be very large; this is important in the way living organisms are built and function.

Volume of a cell determines the metabolic activity.

WHEREAS

Surface area of a cell determines the rate of exchange of materials and heat with the environment.

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IMPORTANCE OF SA:VOL RATIO

- Materials travel in cells by ***diffusion***, which is only effective over short distances.
  - Example: a small molecule like glucose can cross a 50 µm plant cell in 2.5 seconds; for the same molecule to travel 1m (the height of a plant) would take 32 years!

This explains why:

- cells are microscopic
- cells can never grow to large sizes
- this is a contributing factor to the evolution of multi-cellularity
- multicellular organisms are made of millions of small cells rather than one giant one
- when cells reach the maximum surface to volume ratio allowable, they DIVIDE
- a cell needs enough surface area to "service" its volume

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SA:VOL RATIO LIMITS CELL SIZE

- Small cells have larger **SA:Vol** ratio than larger cells.
- As a cell grows, the volume increases faster than the surface area.
- OR, the **SA:Vol** ratio **decreases** as size increases.

Organism	Length		SA (m^2)	vol (m^3)	SA/vol (m^{-1})
Bacterium	1 mm	(10^{-6} m)	6×10^{-12}	10^{-18}	6,000,000
Amoeba	100 mm	(10^{-4} m)	6×10^{-8}	10^{-12}	60,000
Fly	10 mm	(10^{-2} m)	6×10^{-4}	10^{-6}	600
Dog	1 m	(10^{0} m)	6×10^{0}	10^{0}	6
Whale	100 m	(10^{2} m)	6×10^{4}	10^{6}	0.06

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SA:VOL RATIO LIMITS CELL SIZE

- Surface area (membrane) must be large enough to absorb nutrients and oxygen.

AND to excrete waste products and expel heat fast enough to meet the needs of the cell.

- So a large cell has less surface area to bring in essential materials and get rid of waste than a small cell.
- Large animals have more smaller cells instead of larger cells as diffusion is proportional to the surface area of the membrane and is only effective over short distances.
- Larger cells have modifications to increase the SA:Vol ratio, such as villi and microvilli, infoldings or outfoldings (see later).

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EMERGENT PROPERTIES OF MULTICELLULAR ORGANISMS

- Emergent properties arise from the **interaction** of component parts: the whole is greater than the sum of its parts.

- *Examples*:
  - Surface tension is an emergent property of the interaction of water molecules.
  - Consciousness is a property that emerges from the interaction of nerve cells in the brain.
  - Life itself is an emergent property.

- When individual components in an environment come together to create distinct, collective and interactive properties and functions, the results are called **emergent properties.**

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CELL DIFFERENTIATION & GENE EXPRESSION

- UNICELLULAR organisms carry out ALL the functions of life.
- MULTICELLULAR organisms are large and have to specialize parts of their structure to complete the various functions of life.
- All cells in a multicellular organism arise from mitosis of the **zygote** (fertilized egg); thus they all have exactly the same DNA and genes.
- Cells at the early stages of development can differentiate into any type of cell, depending on chemical gradients, gravity, position in the embryo, and other unknown factors.
- So they **express some of their genes and block others.**

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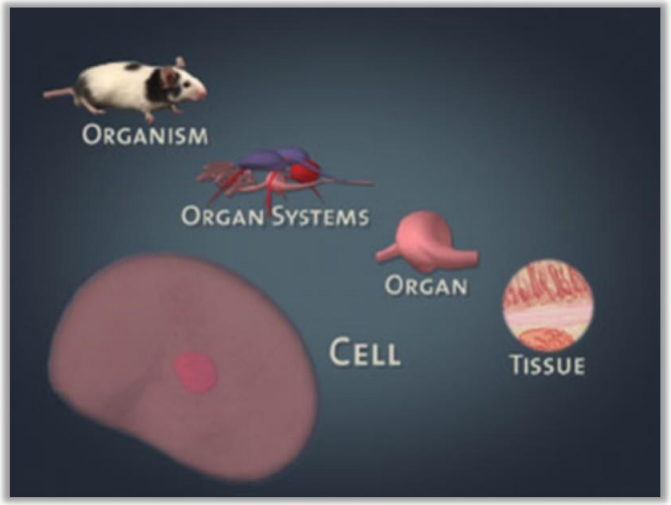
HIERARCHY OF CELLS

- In a multicellular organism, cells are grouped as follows:
- ***Tissue*:** An integrated group of cells that share structure and function.
- ***Organ*:** A combination of two or more tissues, which function as an integrated unit, performing one or more specific functions in an organism.
- ***Organ system*:** A group of organs that specialize in a certain function together.



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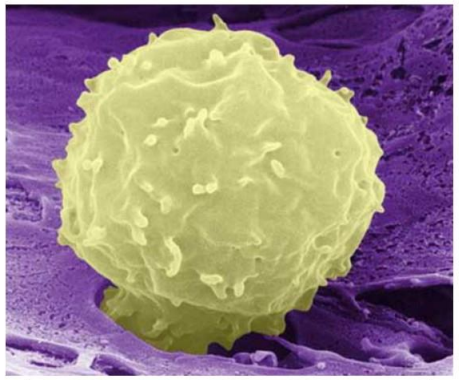
STEM CELLS

- A stem cell retains the capacity to divide and has the ability to differentiate along different pathways.
- Although able to divide it has not yet expressed genes to specialize to a particular function.
- Under the right conditions stem cells can be induced to express particular genes and differentiate into a particular type of cell.
- Stem cells have a large nucleus relative to the volume of the cytoplasm.



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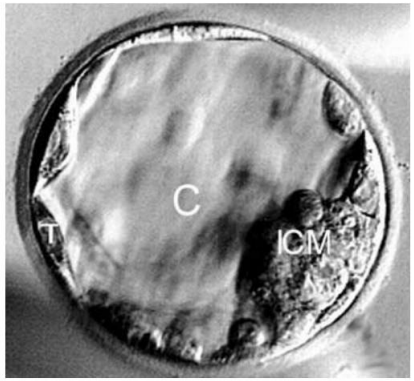
SOURCES OF STEM CELLS

- Stem cells can be obtained from the **blastocyst** (hollow ball of cells formed a few days after fertilization in humans); **Embryonic Stem Cells.**



- Even the placenta and/or umbilical cord blood can be useful sources of stem cells; **Cord Blood Stem Cells**

- Adults still possess stem cells in some organs but much less so than a child ex. bone marrow; **Adult Stem Cells**

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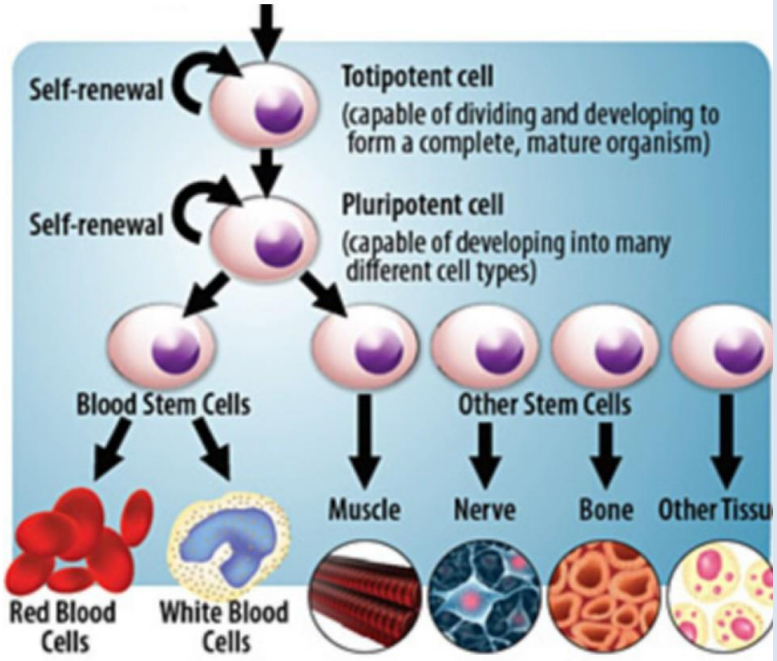
POTENTIAL OF STEM CELLS

- **Totipotent**: a single cell divides and produces all the differentiated cells in an organism, including extraembryonic tissues (ex. spores, zygotes).
- In some organisms, cells can de-differentiate and regain totipotency. For example, a plant cutting or callus can be used to grow an entire plant.
- **Pluripotent**: a cell can create all cell types except for extraembryonic tissues (i.e. can give rise to any of the three germ layers, ex. embryonic stem cells).
- **Multipotent:** Many progenitor cells are multipotent, i.e. they are capable of differentiating into a limited number of tissue types.



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ETHICS AND STEM CELLS

- Use of embryonic stem cells involves the death of early-stage embryos, but if therapeutic cloning is successfully developed the suffering of patients with a wide variety of conditions could be reduced.
    - UK: Licensed research can only take place on embryos up to 14 days. Stem cells are isolated from the **blastocyst**, an early stage embryo that is 5-6 days old. The blastocyst cannot develop into a fetus unless it is implanted into a woman.
- National governments are influenced by local, cultural and religious traditions, which vary greatly, and these, therefore, have an impact on the work of scientists.
- The huge opportunities of therapeutic cloning must be balanced against the considerable risks—for example, stem cells developing into tumors.
- Another issue is how the scientific community conveys information about its work to the wider community in such a way that informed decisions about research can be made.

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THERAPEUTIC USE OF STEM CELLS

- In neurological diseases, such as Parkinson's disease, Alzheimer's disease.

  In 2005, stem cells were used to restore the insulation tissue of neurons in laboratory rats, resulting in subsequent improvements in their mobility.

- In diabetes (replacement of pancreatic cells by stem cells)

- Use of tissue-specific cells in treatment of blood cancer like leukemia or non-Hodgkins Lymphoma by autologous stem cell transplantation.

- In 2010, scientists in Seattle, USA managed to alter a signaling pathway in the stem cells so they could increase in number without losing stem cell properties.

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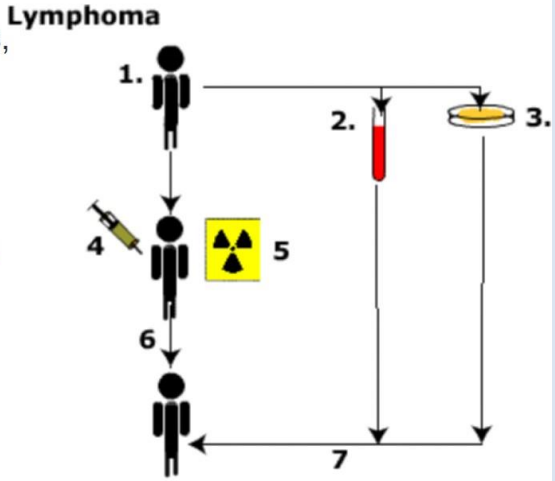
STEM CELL THERAPY FOR CANCER PATIENTS

1. Patient requires heavy doses of radiation and/or chemotherapy. This will destroy health blood tissue as well as the diseased tissue.
2. Blood is filtered for the presence of peripheral stem cells, cells in the general circulation that can still differentiate into different types of blood cells.
3. Fluid from bone marrow is removed before treatment.
4. Chemotherapy supplies toxic drugs to kill the cancerous cells.
5. Radiation can be used to kill the cancerous cells but in time they adapt to this treatment so that radiation and chemotherapy are often used together.
6. Post radiation/chemotherapy the patient's health blood tissues are also destroyed.
7. Healthy stem cells or bone marrow cells can be transplanted back to produce healthy blood cells again (autologous transplantation).



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PAST PAPER QUESTIONS

1. Explain how the surface area to volume ratio influences cell sizes. [3]

2. Outline the differentiation of cells in a multi-cellular organism. [4]

3. Discuss possible exceptions to the cell theory. [4]

4. List examples of where the concept of emergent properties can be found in a multi-cellular animal, such as bird or a flowering plant. [3]

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MARK SCHEMES

1. small cells have larger ratio (than larger cells) / ratio decreases as size increases;
surface area / membrane must be large enough to absorb nutrients / oxygen / substances needed;
surface area / membrane must be large enough to excrete / pass out waste products;
need for materials is determined by (cell) volume;
cell size is limited (by SA / VOL ratio) / cells divide when they reach a certain size;
reference to diffusion across / through membrane / surface area;

[3]

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2. differentiation is development in different / specific ways;
cells carry out specialized functions / become specialized;
example of a differentiated cell in a multicellular organism;
cells have all genes / could develop in any way;
some genes are switched on / expressed but not others;
position / hormones / cell to cell signals / chemicals determine how a cell develops;
a group of differentiated cells is a tissue; **[4]**

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3. skeletal muscle fibres are larger / have many nuclei / are not typical cells;
fungal hyphae are (sometimes) not divided up into individual cells;
unicellular organisms can be considered acellular;
because they are larger than a typical cell / carry out all life functions;
some tissues / organs contain large amounts of extracellular material;
ex. vitreous humour of eye / mineral deposits in bone / xylem in trees / other example;
statement of cell theory / all living things / most tissues are composed entirely of true cells; **[4]**

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4. Bird: nerves and muscles interact to help it fly or eat

   Plant: different cells interact to keep it in upright position or regulate photosynthesis and respiration (guard cells, chloroplasts)