Cell Theory

Stephen Taylor
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"Chisai Benjo" Electron Micrograph
Episode 1: The Hidden Kingdom

Part 2: http://www.youtube.com/watch?v=qm390nEOfIA
Part 3: http://www.youtube.com/watch?v=C7LZfTAZQjs
Part 4: http://www.youtube.com/watch?v=zqjQBZUpKrA
Part 5: http://www.youtube.com/watch?v=FWVIG1NFIDY
Part 6: http://www.youtube.com/watch?v=jYCHsEUO-3U

Episode 2: The Chemistry of Life

http://www.youtube.com/user/AtheistPlanetBlog#g/c/F92B19E07759EFA1

Episode 3: The Spark of Life

http://www.youtube.com/user/AtheistPlanetBlog#g/c/BE06580BE9D711B4
Cell theory has three basic principles:

All living things are made of cells.
- Multicellular organisms have specialised cells to carry out various functions.
- Are unicellular organisms 'made of cells'?

Cells are the smallest units of life.
- Organelles carry out various metabolic functions in the cell
- Cell components cannot survive alone

Cells come only from other cells.
- Louis Pasteur refuted the idea of spontaneous generation with his experiments
- Cells multiply by division
  - Mitosis and meiosis in eukaryotes
  - Binary fission in prokaryotes
- All cells descended from simpler common ancestors
Cell theory is a great example of the scientific process

Observation
- Hooke's observed cork cells
- van Leeuwenhoek's bacteria

Hypothesis
- "Cytoblasts build cells"
- "Living things are made of cells"
- "Cells are the smallest units of life"
- "Cells come only from other cells"
- "Vital energy is the source of life"
- "Life generates spontaneously"

Test
- try again

Refute
- "Vital energy is the source of life"
- "Cytoblasts build cells"
- "Life generates spontaneously"

Evidence
- Microscope observations:
  - light microscopes
  - TEM and SEM (modern)
- Culture growth
- Pasteur's experiments
- Remak's discovery of cell division

Corroborate
- "Living things are made of cells"
- "Cells are the smallest units of life"
- "Cells come only from other cells"

Theory

repeat
Evidence for cell theory: "All living things are made of cells"

Robert Hooke (1635 - 1703)
Pioneering microscopist, optics enthusiast and coiner of the term "Cell" following his drawings of cork sections under a microscope (1655).

Antonie van Leeuwenhoek (1632 - 1723)
"The Father of Microbiology"
Master lens-maker - used them to analyse quality of the cloth made in his factory. He discovered 'animalcules' in water, wrote his findings to the Royal Society and eventually became known as the discoverer of cells.

Hooke and van Leeuwenhoek:

First images of sperm and bacteria:

http://www.youtube.com/watch?v=Q2ezDdKyRUc
http://www.euronet.nl/users/warnar/leeuwenhoek.html
Evidence for cell theory: "Cells come only from other cells"

Pastour's experiments:
Debunking spontaneous generation

Throughout the 1700's and 1800's, the idea of spontaneous generation of life (rats from sweaty grain, maggots from meat, etc) persisted - until Louis Pasteur disproved the idea in 1864.

By preventing entry of airborne particles to a nutrient broth, he stopped growth of the culture. Leaving it open allowed microbes to grow. It seems obvious to us, but was a huge step forward for cell biology.

Pasteur’s Test of Spontaneous Generation

In studying chicken embryos, Jewish scientist Robert Remak discovered cell division under the microscope. In 1858, after many years of doubt, his ideas were plagiarised and made popular by his German colleague, Rudolf Virchow.

"Omnis cellula e cellula"
("Cells come only from other cells")
Limitations and exceptions to cell theory

Amoebae (protoctista):
- single cell capable of all life processes
- if there is only one cell, can we say 'made of cells'?

Fungal hyphae:
- very large
- multi-nucleated
- chitin cell wall (not cellulose)
- continuous cytoplasm
  (HL read ahead: plant science!)

Muscle cells:
- multi-nucleated
- very long

Viruses:
- living or not?
- cells or not?
  Can only reproduce when in control of a host cell.

Reading:
Sputnik - the virus of viruses

If viruses can be infected by other viruses, does that provide evidence that they are living?

http://scienceblogs.com/notrocketscience/2008/08/the_virophage_a_virus_that_infects_other_viruses.php

http://www.healthinitiative.org/HTML/hiv/firstcontact/hivbig.htm
All living organisms carry out the **functions of life**

- **Nutrition**
- **Reproduction**
- **Movement**
- **Excretion**
- **Growth**
- **Response to stimulus**
- **Homeostasis**

**Unicellular organisms**, such as amoebae, are capable of all of these functions.

**Multicellular organisms** have specialised cells to carry out some of the functions and not others - but as a whole, all functions are covered.

There is some debate on the classification of **viruses**, as they cannot carry out all of the functions independently - they must invade a host and use the host cell's apparatus to survive. They can be considered **acellular**.
Given the right conditions, cells can thrive outside their original environment.

Skin tissue culture, from:
http://www.stopanimaltests.com/feat/gta/body2.html
What is the magnification of the image when we view it down the compound microscope?

Multiply these values together

e.g.

\[
\text{eyepiece } \times \text{ objective } = 10 \times 40 = 400 \times \text{ magnification}
\]
Standard International (SI) units of measurement:

<table>
<thead>
<tr>
<th>Unit</th>
<th>Abbr.</th>
<th>Metric Equivalent</th>
</tr>
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<tbody>
<tr>
<td>kilometer</td>
<td>km</td>
<td>1 000 m</td>
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<tr>
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<td>m</td>
<td>1 m</td>
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<tr>
<td>centimeter</td>
<td>cm</td>
<td>0.001 m</td>
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<td>mm</td>
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<td>m</td>
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<td>centimeter</td>
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<tr>
<td>millimeter</td>
<td>mm</td>
<td>0.001 m</td>
</tr>
<tr>
<td>micrometer</td>
<td>μm</td>
<td>0.000 001 m</td>
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<tr>
<td>nanometer</td>
<td>nm</td>
<td>0.000 000 001 m</td>
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</tbody>
</table>
Calculations in microscopy

Use these calculations to find the magnifications or actual sizes of images.

1. Convert all units to make them the same (where appropriate)
2. Perform calculations
3. Convert answers to appropriate SI units, using scientific notation where needed.

- **magnification** = \( \frac{\text{measured length}}{\text{scale bar label}} \)

  e.g.
  
  \[
  \text{magnification} = \frac{30\text{mm}}{2\mu\text{m}} = \frac{30000\mu\text{m}}{2\mu\text{m}} = \frac{30000\mu\text{m}}{2\mu\text{m}}
  \]
  
  \[
  \text{magnification} = 15000 \times
  \]

- **actual size** = \( \frac{\text{measured length}}{\text{magnification}} \)

  e.g.
  
  \[
  \text{actual size} = \frac{450\text{mm}}{15000} = \frac{450\text{mm}}{15000} = 0.03\text{mm}
  \]
  
  or \( 3.0 \times 10^2 \mu\text{m} \)
If you have a scale bar and want to find the actual size:

What do we already know?

- Image length = 50mm
- Scale bar image = 13mm
- Scale bar represents 20µm

Two methods you could use

A. Calculate magnification first, then actual size

\[
\text{magnification} = \frac{\text{measured length}}{\text{scale bar label}} = \frac{13000\mu m}{20\mu m} = 650x
\]

\[
\text{actual size} = \frac{\text{measured length}}{\text{magnification}} = \frac{50}{650} = 76.9\mu m
\]

B. Factor the scale bar against the measured image

\[
\text{size} = \left(\frac{\text{Image length}}{\text{Scale bar image}}\right) \times \text{scale}
\]

e.g.

\[
\text{size} = \left(\frac{50mm}{13mm}\right) \times 20\mu m = 76.9\mu m
\]
We might want to know how many times an image has been magnified.

The scale bar represents the 'real' size of the sample in the image, so we only need to work with the scale bar.

First convert your units so that they are all the same:

\[
\text{scale bar measurement} \quad \text{(we just measured)} \quad = \quad \frac{\text{scale bar label}}{\text{('real life' of sample)}} \quad = \quad \text{magnification}
\]
We might want to know how many times an image has been magnified.

The scale bar represents the 'real' size of the sample in the image, so we only need to work with the scale bar.

First convert your units so that they are all the same:

scale bar = μm, so convert ruler to μm

1 mm = 1,000 μm so 20 mm = 20,000 μm

Now we can calculate the magnification:

\[
\frac{\text{scale bar measurement}}{\text{scale bar label}} = \frac{20,000 \, \mu m}{10 \, \mu m}
\]

magnification = 2,000 times
Print this and **calculate the magnification of these scale bars:**

2µm

67µm

100nm

100µm

50µm

50mm

500m

Remember - for '**calculate the magnification**' questions, the image is irrelevant as long as you have a scale bar.
CALCULATING ACTUAL SIZE (NO SCALE BAR)

For this type of question, simply measure the part of the image you are instructed to and divide it by the magnification.

Convert to the most appropriate units.

e.g. measured length
magnification
CALCULATING ACTUAL SIZE (NO SCALE BAR)

For this type of question, simply measure the part of the image you are instructed to and divide it by the magnification.

Convert to the most appropriate units.

\[
\text{e.g. } \frac{\text{measured length}}{\text{magnification}} = \frac{80\text{ mm}}{90,000} = 8.9 \times 10^{-4}\text{ mm}
\]

or \(0.00089\text{ mm}\)

converts to: \(0.89\mu\text{m}\) or \(890\text{ nm}\)
1. A student views an image of a cell magnified 350 times. The image is 250mm long. What is the actual length of the sample in the image?
1. A student views an image of a cell magnified 350 times. The image is 250mm long. What is the actual length of the sample in the image?

If you're stuck, draw it out...

Actual length = \frac{\text{image length}}{\text{magnification}}

= \frac{250\text{mm}}{350}

= 0.71\text{mm}^*

(or 7.10 \mu m)

* Isn't that a bit big for a cell? More on size of cells later...
2. A sperm cell has a tail 50μm long. A student draws it 75mm long. What is the magnification?
2. A sperm cell has a tail 50\(\mu\)m long. A student draws it 75mm long. What is the magnification?

If you're stuck, draw it out...

1. Convert mm to \(\mu\)m:

\[
75\text{mm} = 75,000\mu\text{m}
\]

2. drawing length

scale bar label

\[
= 75000/50
\]

\[
= 1500 \times \text{magnification}
\]
Arrange these items from largest to smallest:
Arrange these items from largest to smallest:
All this fits inside a... plant cell (100μm)

10μm

animal cell (15μm)
nucleus (6μm)
ribosome (20nm)
mitochondria (3μm)
membrane thickness (10nm)
bacterium (1μm)
virus (100nm)
molecules (1nm)

electron microscope (SEM or TEM)
http://click4biology.info/c4b/2/cell2.1.htm

compound light microscope

naked eye/magnifying glass

http://www.cellsalive.com/howbig.htm
Microscopy resources:

**Bugscope**
Send samples and control the SEM for free!
http://bugscope.beckman.illinois.edu/

**ASPEX Corporation**
Send in samples to be scanned for free!
http://www.aspexcorp.com/resources/send_sample.html

**Free virtual electron microscope!**
http://virtual.itg.uiuc.edu/

**Microscopy-UK**
Virtual electron microscope from Discovery School
http://www.microscopy-uk.org.uk/

**3D SEM images**
Pollen on Bee
http://www.scharfphoto.com/3D/archives/000669.php
Big cells vs small cells

How many units of membrane are there per unit volume?

<table>
<thead>
<tr>
<th></th>
<th>volume</th>
<th>27</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SA</td>
<td>54</td>
</tr>
<tr>
<td>6</td>
<td>SA:Vol</td>
<td>2:1</td>
</tr>
</tbody>
</table>

The plasma membrane is responsible for import/export in the cell. Metabolic reactions occur on membranes.

A larger SA:Vol ratio means the cell can act more efficiently: for every unit of volume that requires nutrients or produces waste, there is more membrane to serve it.
How else is a large SA:Vol ratio a benefit?

Diffusion pathways are shorter, so more efficient - molecules do not have to travel so far to get in/out of the cell, so it takes less time and (if it is active transport) energy. **Concentration gradients are easier to generate** - which makes diffusion more efficient. (i.e. it takes less solute to make 10% solution in a 100ml beaker than a 10l bucket)

A large SA:Vol ratio is not always an advantage:
Small, warm-blooded mammals lose heat very quickly due to their large SA:Vol ratio. They need to eat almost constantly! (Think about how hungry you get on a cold day)

Desert plants would lose water quickly with flat leaves - so they minimise their SA:Vol ratio in order to conserve water. Some plants change their metabolism (CAM plants) to save water.
So how do organisms maximise SA:Vol ratio?

As organisms grow, cells divide. Two small cells are more efficient than one large cell. This also allows for cell differentiation, specialised functions and more complex multicellular life.

**Cells compartmentalise** - they use membranes to carry out metabolic processes. In eukaryotes, these are called **organelles**.

Organelles themselves, like this mitochondrion, are also made up of membranes - maximising the surface area for reactions.

Some **organs** (such as the intestines) fold up to maximise SA:Vol ratio - making absorption of food molecule more efficient. **Alveoli in the lungs** are thin membranes that maximise the surface for gas exchange. Roots are long, and branched, with **root hairs** on the cells to maximise the surface area for water uptake.
Big cell exceptions

Giant bacterium with many genomes:

[Image]


Algae of the genus *Caulerpa* are actually giant single-cells with many nuclei.

[Image]

http://www.reefcorner.com/SpecimenSheets/caulerpa.htm

Remember this for the Prokaryotes topic.

Remember this for the *invasive species* part of the Ecology & Conservation unit.
The discipline of **Systems Biology** looks at the way different parts of a whole organism interact with each other to give emergent properties.

This is a relatively new field, where science has been traditionally reductionist - breaking things down into their component parts. By looking at the whole system, we can see that an organism is **more than the sum of its parts**.

In this diagram, we see that when this specific combination of molecules and pathways are combined, the ability to carry out aerobic respiration emerges.

**Emergent properties** are seen at every level of increasing complexity, from the atom to the molecule, to the cell, to the organism to the biosphere.

TOK: How does the failure of one or multiple systems bring about the death of an organism?

One of the main hurdles to AI is the issue of emergent properties: in biosystems, they 'appear' and if they are not detrimental are selected through evolution. Swarm technology is an example of how scientists are trying to generate software that mimics this process.

EMERGENT PROPERTIES:
When we break something complex into its component pieces, they each appear to be simple. Combined, they can perform a whole new function.

cell organelles
\[\begin{array}{c}
\text{nucleus, mitochondria, ribosomes...} \\
\end{array}\]
cells
\[\begin{array}{c}
\text{muscle cells} \\
\end{array}\]
tissues
\[\begin{array}{c}
\text{cardiac muscle} \\
\end{array}\]
organs
\[\begin{array}{c}
\text{heart} \\
\end{array}\]
organ systems
\[\begin{array}{c}
\text{circulatory system} \\
\text{digestive system} \\
\text{skin} \\
\end{array}\]
organisms
\[\begin{array}{c}
\text{mammal} \\
\text{mammal} \\
\text{mammal} \\
\end{array}\]
Evolution: The Blind Watchmaker

What do the components of the watch do individually?

What do they do when they are put together in the right way?

This is an example of **emergent properties**: the whole is more than the sum of its parts.

One analogy used for evolution is that of the **blind watchmaker**.

Given millions of years and infinite mutations and combinations, it is inevitable that even complex structures will emerge.

There is no purpose or design to evolution - beneficial mutations in a particular environment will allow the organism to survive and reproduce.

http://www.mkibby.com/partsofawatch.html
Stem cells retain the capacity to divide

**Totipotent:** can become any cell type

**Pluripotent:** can become any type except embryonic membrane

**Multipotent:** can become a number of different cell types

**Unipotent:** can only become one cell type

**Nullipotent:** cannot divide (red blood cells)

Differentiation depends on the activation of genes in sequence, often triggered by environmental change.

Once a stem cell has differentiated, it can only make more stem cells or the differentiated cell type.

http://www.csa.com/discoveryguides/stemcell/overview.php
Cell differentiation is a result of **expression of different genes**.

All cells in the body carry the same genes in their nuclei.

What makes a cell different is which genes are expressed - which are turned on or off.

This is triggered by changes and the environment around the cell.
Stem Cell Transplants: Treatment of lymphoma

In the treatment for lymphoma, bone marrow is destroyed in chemo- or radio-therapy. Before this aggressive treatment takes place, stem cells are harvested from the bone marrow and stored.

These harvested cells can be used to replaced the damaged bone marrow, producing healthy blood cells in the recovering patient.
Therapeutic Cloning of Stem Cells:

Therapeutic cloning involves the in-vitro culturing of tissues using patient or donor stem cells. It can be used to replace tissues lost in disease, burned skin or even nerve cells.

http://whyfiles.org/148clone_clash/images/thera_diagram.jpg

Embryonic stem cells are derived from blastocysts — embryos that are about a week old. At this stage, the blastocyst has about 100 cells. Human blastocysts like this have been donated to research from in vitro fertilization clinics.

source unknown

Trachea grown with stem cells:
http://www.youtube.com/watch?v=XL72Dn3rJ_E

Because embryonic stem cells are the most versatile, they have been at the centre of research and controversy.
Embryonic stem cell culture:

- Newly fertilised
- Blastocyst
- Inner cell mass
- Culturing of stem cells
- Undifferentiated embryonic stem cells
- Genetic triggers
- Specialised cells

iPS Stem cells may reduce the need for embryonic stem cells

'induced pluripotent': Differentiated cells can be reprogrammed to return to stem-like states

iPS stem cell culture cures sickle cell in mice:

Using four genes, differentiated cells can be reprogrammed, to restore their potential for cell division.


iPS cells used to make human neurons and treat patients:

http://scienceblogs.com/notrocketscience/2008/08/stem_cells_created_from_als_patient_and_used_to_make_neurons.php
A stem cell is an unspecialised cell type. When it divides it can either produce identical daughter cells (self-renewal) or it can produce more specialised cell types (differentiation). A central goal in stem cell research is to understand how this choice between self-renewal and differentiation is determined.

http://www.eurostemcell.org/

http://learn.genetics.utah.edu/units/stemcells/whatissc/


http://stemcells.nih.gov/info/basics/
What are stem cells?

What are some different types of stem cells?

How does a baby grow up to be a child?
How does a child grow up to be an adult?

The human body relies on a constant process of renewal to develop, maintain and repair itself throughout life. Stem cells are the basic building materials for these processes.

In *What is a Stem Cell?*, we saw that stem cells can become all different kinds of cells, including nerves, muscles, blood, bone and skin. The body uses several different types of stem cells to do this. Let’s explore a few of them:

Be sure to check out the quiz clues to prepare for the quiz on stem cell types!

http://learn.genetics.utah.edu/content/ttech/stemcells/sctypes/

Use the Learn.Genetics site to find out lots more about cells, stem cells and genetics

http://learn.genetics.utah.edu/
"Do I have to declare a major? Couldn't I just be a stem cell?"

For more IB Biology resources:
http://sciencevideos.wordpress.com