INCOMPLETE TEACHING DRAFT, originally created in WordPerfect and converted several years later to Word and subsequently to PDF. Consequently, some format shifting has occurred.

Toqwa'tu'kl Kjijitaqnn / Integrative Science

ThoughtTraps 2 **for:**

MSꟾT 201 / 203

WAYS OF KNOWING

☺

☺☺☺

☺☺☺☺

MSꟾT Course Manual
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(written by Cheryl Bartlett)

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* some articles and inserts will be handed out in class

UCCB Academic Calendar Description for MSIT 201/203

Course title: Ways of Knowing

Mi'kmaq world view: This course will provide an opportunity for students to appreciate that Spiritual connectedness is deeply embedded in First Nations' thought and that the animate / inanimate usage of the language is the shuttle between the traditional, imaginary, spiritual, and physical worlds. The Mi'kmaq conceptual world view is one pathway (or *Way of Knowing*) for the learner to develop levels of sensitivity, introspection, and creativity, and the concepts offered in this course require that students be open and ready to understand. Discussion will involve the Spiritual Ecology of Indigenous education, and four of its six foundations, namely the Visionary, Artistic, Affective, and Communal.

Western science: The concept of connectedness can serve as Common Ground between Western science and Indigenous conceptual world views, as it is embedded in Western science which strives to view the natural world as consistent and complete, and uses mathematics as its symbolic language to express relationship and wholeness. The course will discuss Western science as a *Way of Knowing,* its analytical and reductionist way of viewing the world, its recognition of the importance of details and patterns and use of mathematics, its constraints and general incapacity to deal with concepts of a "soul" in Nature, its fluid frontiers and reliance on creative and imaginative thought in the probing of them, and its unity and major theories in modern cosmology, physics, chemistry, geology, and biology. Students will design, undertake, and complete a project.

Symbols used in the ThoughtTraps

☺ human, or human consciousness ... positive involvement or interesting aspect

☹ humans, or human consciousness ... negative involvement or unfortunate aspect

◙ function of a structure

✄ is something missing in this explanation?

☞ pay attention to, or a conclusion, or a summary point, or related to

✍ new understandings starting to accumulate in Western science

♧ spirituality

✪ example

✳ important point ... note it

? question ... ask yourself

❐ your textbook, or another source ... read it!

❖ drawing ... look at one

♅ metaphor ... one is provided OR you create one

ℭ story ... one to add context to, or enhance, your understanding

⊕ map ... create one

⧗ be creative!

WESTERN SCIENCE

"Big Questions" in the five major natural science disciplines

☺ MSꟷT 201/ 203 considers these "Big Questions" (plus many little ones associated with them) ... and their answers. Upon completion of both courses, you should be able to discuss the five major disciplines in natural science in terms of what their "pursuit" is about and what they have "caught" in terms of "modern scientific knowledge".

- **Cosmology** ... Big Bang Theory
  - How did our Universe originate?
  - How did our Universe evolve?
  - What is the overall structure of our Universe today?
  - What is the destiny our Universe?
  - As humans, what is our place in the Universe?

- **Physics** ... Building Blocks of Matter and Fundamental Forces of Nature (The Standard Model)
  - What is the Universe made up of?
  - Do "basic building blocks" of ordinary matter exist? What are they?
  - Do "fundamental particles" of ordinary matter exist? What are they?
  - Do "fundamental forces" of energy exist? What are they?

- **Chemistry** ... Periodic Table of the Elements
  - What different kinds of atoms (i.e. elements) are there in the Universe?
  - What properties and relationships exist among different elements?
  - Why do atoms become ions, or come together to form molecules?
  - What happens when particular types of energy conversions occur?

- **Geology** ... Planet Earth
  - How is the matter of the Universe arranged in planet Earth?
  - What are the Earth's building blocks?
  - What are minerals? How do they originate?
  - What are rocks? How do they originate?
  - How do continents form? ... Plate Tectonics Theory

- **Biology** ... Life
  - What is life?
  - What are the major categories of life on Earth? ... Biodiversity
  - How did life originate?
  - How did life diversify? ... Theory of Evolution
  - Do "basic building blocks" of life exist? What are they? ... Cell Theory
  - Where in the cell is the information for life stored, and how is it accessed and used?
  - How do living organisms convert energy?

COSMOLOGY

☺ ... its Big Questions about Nature

1) How did our Universe originate? (Big Bang Theory)

2) How did our Universe evolve? (Big Bang Theory)

3) What is the overall structure of our Universe today? (Roadmap to the Universe)

4) What is the destiny of our Universe?

5) As humans, what is our place in this Universe?

❒ Read: *Integrated Science*

QUESTION: How did our Universe originate?

Answer: The origin, or birth, of the Universe was from a much, much hotter and much, much denser state ... than what we observe today.

What, exactly, this hot and dense state was is not known, but the most accepted suggestion is that is was a "singularity" ... a microscopic speck of *excited vacuum of pure energy* (i.e. an extremely hot, and extremely dense single-point state) ... which then expanded enormously in what is called the Big Bang.

✳ Note: The Big Bang theory does not suggest (or even try to suggest) a source for the excited vacuum of pure energy ... and, this is not considered to be something that can be investigated by science. Thus, it is important to understand that the Big Bang theory describes how the Universe expanded, not how it began. Many people wrongly think that the Big Bang theory describes an explosion that led to our present day Universe ... it does not ... it describes the expansive growth of the Universe (Peebles 2001).

QUESTION: How did our Universe evolve ... i.e. change over time?

Answer: The Big Bang Theory describes the expansive growth of the Universe ... i.e., the emergence of space, time, energy, and matter ... which make up our present day Universe.

The universe today is expanding and cooling ... this is the essence of the **Big Bang Theory** ... and the statement forms the foundations of **Cosmology** as a modern, scientific discipline.

We do not know what the Universe was doing before it was expanding — the leading theory is that the Universe grew out of **inflation**... and, considerable current research is directed towards gathering evidence for this inflationary theory (Peebles 2001).

- Inflation suggests that in the first 10^{-32} seconds of its existence, the Universe expanded at a rate far greater that at any time since. This suggestion comes with other ideas ... such as the possibilities of “a multiverse” (a collection of universes) and “funny energy” (currently unknown forms of energy or matter).

There is also a lot of current thought and some evidence that the expansion of the Universe, as we see it today, is accelerating ... but this **acceleration** theory must be viewed as a work in progress, i.e. the evidence for it is encouraging but incomplete (Peebles 2001).

In contrast to the above two theories (inflation and acceleration), there is abundant evidence for the **Big Bang theory**, i.e. the statement that the Universe is expanding and cooling, including. This evidence includes (Peebles 2001):

1) light from distant galaxies is shifted toward the red
   → as it should be if expansion is pulling galaxies away from one another

2) a sea of thermal radiation fills spaces
   → as it should if space used to be denser and hotter

3) the universe contains large amounts of deuterium and helium
   → as it should if temperatures were once much higher

4) galaxies billions of years ago look distinctly younger
   → as they should be if they are closer to the time when no galaxies existed

5) the curvature of spacetime seems to be related to the material content of the Universe
   → as it should be if the Universe is expanding according to the predictions of Einstein’s *general theory of relativity*

Big Bang Theory ... the story of the growth of the Universe ... ***in mathematical language*** ...

☞ is Einstein's **general theory of relativity** (GR). It is (Albright 2000):

- a completely adequate descriptor of gravity.

- a "classical field theory" ... i.e., one in which it is possible to know both the position and momentum of a particular object at the same time.

- incompatible with the uncertainty principle of quantum mechanics (QM) theory ... where it is not possible to know position and momentum simultaneously. QM is needed to explain the extremely early universe when matter was very tightly compacted.

QUESTION: What is the overall structure of our Universe today?

Answer: When we look at "the parts that make up the whole of the Universe" ... we find that:

- galaxies, some very similar to our own Milky Way and some shaped a bit differently, are found at the largest distances that can be investigated with the instruments of modern science (Albright 2000).
- the Universe consists of matter and energy ... as follows (Ostriker and Steinhardt 2001) ... due to rounding, the figures do not add up to 100%:

- **dark energy** ... about 70%
  - ✳ Dark energy is not well understood ... but the leading ideas are that it consists of either:
    - a cosmological constant, or
    - a quantum field known as quintessence

  Dark energy is characterized by its *repulsive gravity*.

- **dark matter** ... about 26%
  - ✳ Dark matter is composed of exotic elementary particles.
  - ✳ Dark mater makes up most of the mass of the Universe (Peebles 2001).
  - ✳ Dark matter is clumped around the outer parts of galaxies (Peebles 2001).

- **ordinary matter** ... about 4% ... as:
  - visible matter 0.5%
  - invisible matter 3.5%

- **radiation** (of the four fundamental forces) ... about 0.005%

***a concept map for the Universe*:** Energy dancing in Spacetime in Matter and Forces

Universe → matter → ordinary matter → visible matter
↘ invisible matter
↘ dark matter
↘ energy → fundamental forces (radiation)
↘ dark energy

CHART: the Big Bang

... a model that starts with an eruption from a point-like singularity (15 bya)

— VACUUM ERA

microscopic speck of excited (unstable) vacuum of pure energy
• four-dimensional spacetime with all forces unified (*theory of everything*)
↓

vacuum energy develops an intensely <u>repulsive</u> gravity that blows itself apart
• inflation ??????????
↓
BIG BANG begins = cosmic expansion
• quantum fluctuations in the vacuum
↓

— RADIATION ERA

vacuum energy shifts state (= transforms itself) **... conversion into radiation energy**
• creation of light, i.e. radiation (photons)
• ***gravity*** separates out ... adopts its familiar <u>attractive</u> behaviour
(other forces remain as one ... *grand unified theory*)
↓
• creation of matter and anti-matter (particles and anti-particles ... in equal numbers)
• creation of dark matter (which dominates the mass of today's universe)
↓
creation of baryonic matter ... = "quark soup" (quark plasma) ... more matter than anti-matter
→ **quarks and leptons**
• excess of quarks and leptons over anti-quarks and anti-leptons (true of today's universe)
↓
10^{-10} sec
radiation energy shifts state ... conversion into rest mass of matter particles
• ***strong nuclear force*** separates out (end of supersymmetry in universe)
• unification of electromagnetic and weak forces (electroweak force)
✳ *threshold of currently tested laboratory physics*
↓

10^{-4} sec

transition of matter ... from "quark soup" to hadronic matter (i.e. formation of neutrons and protons)
→ **hadrons**
• creation of additional dark matter
↓

1 sec

electromagnetic force and ***weak nuclear force*** decouple
• neutrons and protons stop changing back and forth into each other
→ protons come to outnumber neutrons 7:1 (true of today's universe)
↓

100 sec

1st nucleosynthesis (nuclear fusion): from H^+ some ^2H (deuterium), mainly He (helium), a little Li (lithium)
→ **1st nuclei**
↓

10,000 yrs

equality of matter and radiation ... matter dominates mass
↓

500,000 yrs

decoupling of matter and radiation ... universe transparent to light
→ **^1H atoms**
↓

— MATTER ERA

0.5-2 bya

condensation of matter clouds (^1H, ^2H, He, Li) to form 1st stars and 1st galaxies
• nucleosynthesis in these "fusing stars" of elements up to $_{26}Fe$
• stellar evolution: total consumption of fuel (^1H, ^2H, He) in core of fusing stars ...
... leading to formation of red giants, neutron stars, black holes, supernovas
↓
in supernovas (explosion of fusing stars) ... nucleosynthesis of remaining elements (to $_{92}Ur$)
↓
condensation of "star dust" to form our solar system, our sun (a 2nd generation star), our planets
↓

3.9 bya

origin of life on Earth

• evolution of life on Earth, including humans

Separation of the four fundamental energy forces and formation of the fundamental matter particles

Energy forces

Four fundamental energy forces are recognized ... and ... they change from a single, unified force prior to the Big Bang ... to their separate four forms in its aftermath ... in the following order:

- first to separate out: gravity
- next to separate out: strong nuclear force
- last to separate from each other: electromagnetic and weak nuclear

A possible fifth type of energy ... so-called "dark energy" ... is not well understood ... and there are various suggestions as to when it separated out.

Matter

energy: separation into fundamental matter particles

- leptons and quarks

Formation of atoms of the elements

Question: **Where did the various elements originate?**

Answer: Using the numbering system for the elements, as found in the Periodic Table ...

- #1-3: origin: in the early aftermath of the Big Bang
- # 3 - 26: origin: in fusing stars
- #27 - 92: origin: in supernovae
- #93 - 116: origin: in labs of modern scientists

☞ **nucleosynthesis ... the natural process of element formation occurring in stars**

- is the synthesis (making, production) of new nuclei for elements of higher and higher mass via combining H (mainly) with other elements
- because it occurs via a combining process ... it is also called "nuclear fusion"
- is the major event occurring in stars
- is an event accompanied by the release of tremendous amounts of extremely high energy ... in the form of electromagnetic radiation (e.g. the "sunshine" that reaches Earth) and nuclear radiation
- is the natural process that humans have unleashed in nuclear bombs (H bombs)

Formation of stars

Question: How do stars form?

Answer: an answer in the form of "star life cycles" (Ridpath 1998, Maran 1999)

Cosmologists suggest that stars are born and die, i.e. that they have **life cycles** with different stages. For ease in understanding, we can refer to these different life stages as:

- birth
- baby
- adult
- senior
- dying

birth: a huge cloud of hydrogen gas and dust in space (called a **nebula**) begins to shrink under the inward pull of its own gravity, creating a ...

baby star: which is more technically called an embryonic star or protostar. Shrinkage continues until ... the density and temperature at the centre (or core) become high enough to cause nuclear reactions to begin (fusion of hydrogen to helium). At this point, an embryonic star "switches on" to become an ...

adult star: which is now a true star in that it generates its own heat and light. Such a star is technically referred to as being "on the main sequence", or a **main sequence star**. It steadily burns (via nuclear fusion) the hydrogen at its core. What happens next depends directly on what the star was born with ... i.e. its initial mass. There are three possibilities:

1) <u>medium initial mass</u> ... which is our Sun and others similar to it. The star burns the hydrogen in its core until all is used up ... at which point the hydrogen in the larger and surrounding "shell" region ignites. Energy released by burning this hydrogen causes the star to become brighter and to expand (swell) ... making its surface larger, cooler, and redder. It is now referred to as a **red giant** ... which would be a ...

   ... ***senior star***. Its outer layers form a new gas shell known as a **planetary nebula**. However, stellar winds blowing off the star expel this planetary nebula ... leaving the core exposed as a hot **white dwarf** that fades over billions of years. When this ...

   ... ***dying star*** ceases to emit light, it is known as a **black dwarf**.

✺ Our Sun is thought to be half way through its life cycle of about 10 billion years.

2) <u>huge initial mass</u> ... 1-2 to 30 times our Sun. The star burns the hydrogen in its core until all is used up, at which point the hydrogen in the larger "shell" region surrounding the core ignites. The energy released by burning the hydrogen in the shell causes the star to become brighter and to expand (swell) ... making its surface larger, cooler, and redder. It is now referred to as a **red supergiant** ... which would be a ...

... ***senior star***. Its core eventually collapses, causing a huge explosion called a **supernova** which shines extremely brightly for a few weeks ... its outer layers are scattered in space but the fate of the core of the now ...

... ***dying star*** again depends on its mass.
- a low mass core (1-2 times our Sun) will be crushed into a tiny, superdense **neutron star**
- a high mass core (> 2 times our Sun) will be crushed by its own gravity even further, into a **black hole**

→ These stars have relatively short life cycles ... exploding just a few million years after they are born.

3) <u>small initial mass</u>: (~1/10 our Sun). The star steadily burns the hydrogen in its core ... and remains forever as an adult star ... a **red dwarf**.

→ These stars can last for 100 billion years or more.

Formation of the Milky Way Galaxy

Question: How did our Milky Way Galaxy originate?

Answer: Our galaxy, the Milky Way, is thought to have formed by the aggregation (coming together) of gas and stars from a reservoir of preexisting small galaxies in the local universe ("the neighbourhood"). The process is thought to have begun more than 12 billion years ago.

Formation of the planet Earth

Question: How did our planet Earth originate?

Answer:

- formation of elements 1-92 (through natural processes in the Universe) and the spitting of these into space with the explosion of stars

- a cloud of H and He dust in space, together with other elements from supernovae ... begins to shrink under the inward pull of its own gravity

- within this cloud, shrinkage and condensation occur ... forming, about 4.5 billion years ago, a massive object (but not massive enough to burst into flame as in the process that gives rise to stars) ... the "**primitive earth**"

- within this **primitive earth** ... *stratification of the elements* occurs
  → heavier elements sink towards the centre, or core (e.g. Zn, Ni)
  → lighter elements and gases remain near the surface (H_2, He)

  - **1st atmosphere** forms
    - due to: stratification
    - contains: H_2 and He gas [plus N_2, CO_2, HCN (hydrogen cyanide), CH_4]

  - fate of 1st atmosphere: "escapes" because earth's gravitational field at that time too weak to hold it
  - surface of planet left behind: bare and rocky with no atmosphere, no oceans

- as time passes ... earth continues to undergo gravitational compression
  ... this, together with radioactive decay generates enormous heat at centre
  ... results in centre of planet melting (becomes molten, liquid rock)
  → intense heat drives out various gases by way of volcanic action

  - **2nd atmosphere** forms
    - due to: escape of gases from volcanoes
    - contains: again, those gases of 1st atmosphere PLUS H_2S, NH_3, H_2O

  - fate of 2nd atmosphere: retained ... but becomes modified much later
    - note: H_2O present, O_2 absent
    - H_2O vapor cools as it rises, condenses, falls as torrential rain
  - surface of planet:
    - receives torrential rainfall which erode rocky surfaces
    - oceans form as rainwater collects into vast areas ("oceans")
      ... eroded material causes oceans to be salty and mineralized

- early oceans thought to have been thermodynamically stable (and to contain only small molecules and ions)

  → no tendency for molecules to react with each other to form more complex molecules
  → **except ... due to inputs of energy, these oceans do not remain stable** ... and more complex entities (including macromolecules and life forms) emerge

  ✺ sources of energy include:
  - lightning
  - µv radiation
  - radioactive decay
  - volcanoes

Emergence of macromolecules on the planet Earth

☞ see "Biology" section of ThoughtTraps 2 / MSIT 201/203

Emergence of life on the planet Earth

☞ see "Biology" section of ThoughtTraps 2 / MSIT 201/203
→ about 3.9 billion years ago

Emergence of consciousness in living organisms on the planet Earth

☞ see ThoughtTraps 1 / MSIT 101/103

Large celestial objects in the Universe today

Object(s)	What is it (are they)?	What is its (their) origin?
Earth	our planet	condensation of cosmic dust and gases from supernovae
Moon	our moon	matter dislodged from Earth during a collision with an asteroid
Sun	our star	condensation of cosmic dust and gases from supernovae
solar system	our Sun plus all its planets	
planets	Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto	similar to Earth
asteroids	big rocks that orbit our Sun	remnants from the formation of our solar system ... that never combined to form planets
Northern Lights (=Aurora Borealis)	electrons from Earth's magnetosphere that escape and rain down on our atmosphere, striking atoms and molecules and causing them to glow ... as "lights"	
meteoroid	small, solid object in space	usually a fragment from an asteroid or comet, more rarely from our Moon or Mars
meteor ("shooting stars")	the flash of light produced when a small object in space enters Earth's atmosphere	
meteorite	a small object from space that has fallen to Earth	
comet	great blob of ice & dust that slowly travels across the sky like glowing, fuzzy ball with a tail	

stars

North Star
(= Polaris)

star clusters

constellations

galaxies

quasars

normal matter

dark matter

antimatter

cosmic rays

Roadmap to the Universe

⇨ an effort to "map" the **different levels of organization of matter**, as found in the Universe today ... in which we start at the smallest level (fundamental particles) ... and build to the largest (the Universe itself).

⇨ Note: the Roadmap does not show everything!

→ Universe
→ Milky Way galaxy
→ solar system
→ Earth
→ ecosystems
→ communities
→ populations
→ organisms (e.g. humans: *Homo sapiens*)
→ organ systems
→ organs
→ tissues
→ cells (prokaryotic & eukaryotic)
→ organelles
→ big molecules (polymers) [esp. proteins, carbohydrates, nucleic acids, lipids]
→ small molecules (monomers)
→ atoms
→ protons & neutrons
→ subatomic particles (quarks and leptons)

⇨ The different fundamental energy forces *dominate* (i.e. cause "things" to "stick together", to exist, to be) ... at different levels in this Roadmap.

- weak nuclear .... up and down quarks (within protons and neutrons)
- strong nuclear .... protons sticking to neutrons (and gluons sticking to gluons)
- electromagnetic ..... electrons sticking to nuclei (to make atoms) ... to atoms sticking to atoms (to make molecules) ... through molecules to organisms and up
- gravity .... planets sticking to stars (to make solar systems) ... to the whole Universe sticking together *(but still expanding due to the Big Bang)*

QUESTION: What is the destiny of our Universe?

Cosmology offers three distinct answers *as scenarios*, but there is no standard model because there is not enough data to support any one more strongly than the others.

Answer #1: closed ... gravity is strong enough that it will eventually pull the Universe back together in a "Big Crunch"

Answer #2: open ... gravity is not strong enough to pull things together ... so the Universe keeps expanding and as it does so it keeps cooling until everything in the Universe is frozen

Answer #3: flat ... gravity is not strong enough to pull things together ... so the Universe keeps expanding but at the slowest possible rate

QUESTION: As humans, what is our place in this Universe?

We are stardust ... the atoms that make up our bodies came from stars

Hydrogen and helium formed in the early aftermath of the Big Bang, followed by elements # 3 - 26 in the fusing stars and elements #27 - 92 in supernovae.

- All these elements were “spit into space” as debris from supernova ... to eventually (much, much later) be the very same atoms of elements that form into living organisms on the planet Earth (including YOU and all other humans).

- Thus, you are the waste material from ancient stars ... **you are stardust**!

Time line ... from atoms to life to Mi’kma’ki today

- student research project ... insert

PHYSICS

☺ … its Big Questions about Nature

1) What is the Universe made up of?
2) Do "fundamental particles" and "basic building blocks" of ordinary matter exist in the Universe? What are they?
3) Do "fundamental forces" exist in the Universe? What are they?

❒ Read: *Integrated Science*

QUESTION: What is the Universe made up of?

Answer: Energy dancing in Spacetime in Matter and Forces

concept map:

Universe → matter → ordinary matter → visible matter
↘ invisible matter
↘ dark matter
↘ energy → fundamental forces
↘ dark energy

Energy ... what is it?

☞ energy = the "basic stuff" of the universe

- The question "what is energy" cannot be answered directly, as we do not really know. However, it is the "basic stuff" of the Universe.

- the two basic forms that energy takes ... are matter and energy forces ... they are the "dance".

Spacetime ... what is it?

☞ space and time together = *spacetime* ... which is filled with the "dance" of energy

- spacetime is filled with *fields* ... and it is in these fields that the dance occurs

  - the "forms in the dance" (matter and forces) are, more technically, considered to be fields ... and thus, there are two classes of fields (matter and forces)

→ thus, *energy* dances in *spacetime* in *matter* and *forces*

Space ... what is it?

- three dimensions: length, width, height

Time ... what is it?

- the fourth dimension

<u>Energy forces</u> ... what are they?

→ There is energy that Western science understands "fairly" well ...
... namely, the **four fundamental forces** (electromagnetic, strong and weak nuclear, and gravity)

✳ For three of the fundamental forces (electromagnetic, strong and weak nuclear), energy can be said to dance in "quanta" which may be described as like:
- EITHER a *wave* OR a *particle*
- → quantum mechanics (or quantum field theory) <u>connects the wave and particle descriptions</u> of things

✳ The fourth fundamental energy force is gravity ... but physicists have not yet been able to describe it in terms of quantum field theory.

→ There is emerging evidence for a diffuse (very thinly spread out) **fifth energy force** ... that Western science does not understand well ... so-called **dark energy** that may be *dynamical* (i.e. changing with time; and sometimes referred to as "quintessence") or *fixed* (i.e. non-changing; and sometimes referred to as the "cosmological constant").

<u>Force</u> ... what is it?

- the intermediate action through with matter interacts with matter

<u>Matter</u> ... what is it?

- anything that takes up space and has mass (≈weight) ... there are different types:

- **dark matter** ... makes up about 26% of the Universe.
  - ✳ It makes up most of the *mass* of the Universe (Peebles 2001), and is clumped around the outer parts of galaxies (Peebles 2001).
  - ✳ Dark matter is still a mystery, i.e. it is not known exactly what it is made up of ... but there are a number of speculative candidates, including:
    - brown dwarfs (stars with core's that are not hot enough to burn)
    - supermassive black holes (which power distant quasars)
    - new forms (i.e. exotic) of elementary particles

- **ordinary matter** ... makes up about 4% of the Universe ... as:
  - **invisible matter** ..... 3.5% (neutrinos)
  - **visible matter** .... 0.5% (baryonic matter)
    - ✳ there are four different <u>states</u> of ordinary visible matter:
      - gas • liquid • solid • plasma

  - ordinary visible matter is made up of:
    - building blocks (atoms) ... which, in turn, are made up of
    - fundamental particles (quarks and leptons)

The Universe has two realms

1) a realm described by **classical physics** (mechanics)

= systems whose size corresponds to human scale and greater
... often called Newtonian mechanics, or the Newtonian world

→ in classical field theory
- it is possible to know both the position and momentum of a particular particle at the same time ... i.e., behaviours are deterministic ... can predict exactly what will happen next.
- dynamics are non-linear

→ at play ... “Standard Rules of Physics”

2) a realm described by **quantum physics** (mechanics)

= systems whose size corresponds to atomic or smaller scales

→ in quantum field theory
- it is not possible to know both the position and momentum of a particular particle at the same time ... i.e., behaviours are probabilistic ... cannot predict exactly what will happen next.
- dynamics are linear

→ at play ... “Rules of Quantum Mechanics” (see details under “structure of the atom”)

QUESTION: Do "basic building blocks" of ordinary, visible matter exist? What are they?

Answer: Yes, there are **basic building blocks** of ordinary visible matter.
☞ each basic building block is called an **atom**
☞ each basic building block contains (or, is made up of) **fundamental particles** held together by ***fundamental forces***.

Structure of the atom

- **atom**
  ... a nucleus surrounded by electrons
  ... nucleus and electrons bound to each other by electromagnetic forces
- **nucleus**
  ... positive electrically charged protons together with electrically neutral neutrons
  ... protons and neutrons bound to each other by gluonic forces (strong nuclear forces)

☞ The **Rules of Quantum Mechanics** govern the atom.
[http://www.cassfos02.ucsd.edu/public/tutorial/Planck.html]

1) Physical characteristics at the atomic level are **quantized** ... which means they can only have certain, *discrete* values ... e.g. 1 or 2 or 3, not ½ or 1½ or 2½ .

   E.g. The energies available to an atom are limited to specific amounts. Consequently, in the Bohr Model of the atom, this means that only certain orbits are allowed for the electrons (i.e., no intermediate orbits or energies are allowed).

2) Only one particle can occupy a particular state at any one time. This is called the **Pauli Exclusion Principle.**

   E.g. In the first atomic orbit, only two electrons are allowed, one spinning clockwise and one spinning counter-clockwise.

3) Light, protons, electrons, and other particles exhibit both wave-like and particle-like behaviours. This is called the **wave-particle duality**.

4) The Universe is **probabilistic** rather than deterministic.

   E.g. Even if we know everything that there is to no about an atom, we cannot predict exactly what it is going to do next. The laws can only assign "probabilities" ... i.e. likelihoods for specific behaviours.

☞ The quantization of atomic energy levels and the Pauli Exclusion Principle are responsible for the Periodic Table of the Elements (see Chemistry).

QUESTION: Do "fundamental particles" of ordinary, visible matter exist? What are they?

Answer: There are two <u>types</u> of **fundamental particles** of ordinary matter ... called:
1) quarks
2) leptons

The fundamental particles (quarks and leptons) are distinguished by their:
- mass
  - → quarks have a lot of mass .... they are "heavy" particles
  - → leptons have very little mass .... they are "light particles"
- electrical charge
  - → quarks have positive electrical charge
  - → leptons may, or may not, have electrical charge
    - - electrons have negative electrical charge
    - - neutrinos have no electrical charge

☞ Ordinary matter consists of:
- visible matter, and
- invisible matter.

✳ Because quarks and electrons ... have electrical charge ... they interact with light (i.e. electromagnetic energy). And, thus quarks and electrons make up **ordinary, visible matter**.

✳ Neutrinos have no electrical charge ... and do not interact with light. They make up **ordinary, invisible matter**.

☞ For each type of fundamental particle, there also exists another type, of equal mass but with opposite charge ... called an **antiparticle**

Quarks

quarks do not occur alone ... they either occur as:

- 3's ... i.e., as triplets ... one triplet = **baryon**
  - → there are 2 types of baryons: proton and neutron

- 2's ... i.e., as pairs ... one pair = a pion or a meson

→ quarks, since they do not occur alone, must be bound together by something ... the somethings are **gluons** (see strong nuclear force)

→ quarks and gluons together ... i.e., "composite matter" = **hadronic matter** (for heavy mass particle, which contrasts to leptonic matter)

quarks ... come in **6** ***flavors*** (= types), grouped into **3** ***generations***:

Generation #1:	up quark	down quark
Generation #2:	charm quark	strange quark
Generation #3:	top quark	bottom quark
	↑	↑
	electrical charge on each: +⅔	electrical charge on each: -⅓

☺ The matter that makes up our everyday, familiar world is mostly made up of Generation #1 quarks.

Baryons ... two different types

- a **proton** is a baryon with:
  - ... two up quarks (each +⅔), and
  - ... one down quark (-⅓)
  - ... plus force particles (gluons) which hold the quarks together
  - → overall electrical charge on one proton: +1

- a **neutron** is a baryon with:
  - ... two down quarks (each -⅓), and
  - ... one up quark (+⅔)
  - ... plus force particles (gluons) which hold the quarks together
  - → overall electrical charge on one neutron: 0

Leptons

leptons (light mass particles ... "leptonic matter") occur alone

- the familiar "electron" in the atom is a lepton, with an overall electrical charge of -1

leptons ... come in **6** ***favors*** (= types), grouped into **3** ***generations***:

Generation #1	electron	electron neutrino
Generation #2	muon	muon neutrino
Generation #3	tau	tau neutrino
	↑	↑
	electrical charge: -1	electrical charge: 0

☺ The matter that makes up our everyday, familiar world is mostly made up of Generation #1.

Generations of fundamental particles

The three "generations" are sometimes also called "families".

Generation #1 ... familiar, everyday matter (baryonic matter) ... contains:
- up quarks
- down quarks
- electrons
- electron neutrinos

Generation #2 ... contains:
- charm quarks
- strange quarks
- muons
- muon neutrinos

Generation #3 ... contains:
- top quarks
- bottom quarks
- tau leptons
- tau neutrinos

☺ Only particles in the 1^{st} generation are found in our familiar, everyday world ... i.e. are common in the Universe today. Particles in the 2^{nd} and the 3^{rd} generation occurred abundantly in the first microsecond after the Big Bang, and then decayed into the 1^{st} generation.

“Dark matter” in the Universe

Question: What is dark matter?
Answer: It is *exotic* matter (i.e. not ordinary matter) that does not interact with light ... hence the name “dark”.

Dark matter is not well understood ... many lines of indirect evidence suggest that it is made up of **exotic elementary particles** ... but these particles (other than the neutrino of ordinary matter) have yet to be found.

Dark matter makes up most of the mass in the Universe ... and it is clumped around the outer parts of galaxies.

QUESTION: Do "fundamental forces" of energy exist? What are they?

Answer: Yes, they exist ... and modern science recognizes four *fundamental forces*.

1) gravity
2) electromagnetism
3) strong nuclear force
4) weak nuclear force

Question ... what is a "force"?
Answer, by definition: the intermediate action through which matter interacts with matter

☞ each force is transmitted ... by its own **force particles**
☞ each force is experienced ... by "matter particles" that can **couple** to that force

• the force particle for each force has its own name:

1) gravity → graviton
2) electromagnetism → photon
3) strong nuclear force → gluon
4) weak nuclear force → W and Z bosons

• each force has an ability to connect with a particular type of **charge** on a particle of matter ... but, in order to connect to a force, a matter particle must carry the appropriate charge that **couples** to that force ... and becomes a **coupled charge**

1) gravity → couples to ... all energy
2) electromagnetism → couples to ... electrical charge
3) strong nuclear force → couples to ... color ... three flavors: red, green, blue
4) weak nuclear force → couples to ... weak isospin

• when a force connects matter particles that are separated in time and space, it is given the name **radiation** ... thus, each force also has its own type of radiation:

1) gravity → gravitational waves
2) electromagnetism → light
3) strong nuclear force → confined (to the nucleus of an atom)
4) weak nuclear force → short range (not even across the nucleus of an atom)

Most relevant phenomena, in the universe, associated with the four fundamental forces:

Force name	*Strength*	*Force particle*	*Force especially prominent in*
1) gravity	#3	graviton	universe, galaxies, stars, solar system
2) electromagnetism	#2	photon	visible light, atoms, molecules, chemistry, biology
3) strong nuclear force	#1	gluon	atomic nuclei, nuclear energy
4) weak nuclear force	#4	W and Z bosons	element formation, radioactive decay

Synopsis of the four fundamental forces

1) Gravity couples to particles of matter that have energy
→ all particles of matter have energy

- thus, all particles of matter experience gravity
... is the dominating force in the Universe at large (although not the strongest) ... holds together the galaxies, stars, and planets ... and our feet anchored to the spinning Earth
... gravity makes things move toward each other (it is attractive)
... gravity is long-range
... radiation form of gravity = gravitational waves

2) Electromagnetism couples only to particles of matter that have electrical charge
→ only electrons and quarks have electrical charge

- thus, only electrons and quarks experience electromagnetic force
... is responsible for all chemical processes ... formation of all atomic and molecular structures
... electrical charge is either positive or negative
... electrical force is either attractive or repulsive
... magnetic forces arise if there are moving electrical charges
... electromagnetism is long range
... radiation form of electromagnetism = light
... manifests in radioactive γ decay

→ electromagnetic energy interactions:
- *within* atoms .... explains why electrons are attracted to the nucleus
- *between* atoms .... explains why molecules form (via sharing of electrons)

✳ Astronomy is the study of photons that reach Earth from the heavens ... including the struggle to extract information from them (i.e. to make them "talk"). A particular challenge for Astronomy is that the vast majority of the matter in the Universe is "dark matter" ... it does not glow ... i.e., it provides no light, no photons.

✳ Humans live in a "soup" of electromagnetic energy ... both natural and artificial.

✳ some important terms and concepts:
- electromagnetic radiation = energy in transit in the form of high-speed particles and waves
- electromagnetic radiation ... travels at the speed of light (about 300,000 km/sec) [more precisely 297,000 km/sec, or 186,000 mi/sec]
- electromagnetic spectrum = the range of all electromagnetic energy
- visible light spectrum = the range of electromagnetic energy detectable by the human eye

❒ Read: ThoughtTraps 1, "electromagnetic energy" in section about sensation as a building block of consciousness

<u>3) Weak nuclear force</u> couples to all matter particles (i.e. all matter experiences weak force)
... it couples to a charge called weak isospin (which all particles have)
... manifests only in certain kinds of particle collisions ... and in radioactive β decay

<u>4) Strong nuclear force</u> couples only to quarks and gluons
... it holds the protons and neutrons together in the atomic nucleus
... is the force that powers the sun ... and the force unleashed by the hydrogen bomb
... manifests in radioactive α decay

<u>important additional points</u>

- gluons .... also couple to themselves
- quarks .... all the forces couple to them
- leptons .... only gravity, electromagnetism, and weak nuclear forces couple to them

<u>important additional understandings ... particles, fields, forces, and radiation</u>

- these are all the <u>same</u> entity (*energy*) but in different contexts

- a **force particle** ... creates a disturbance in the spacetime around it
  - this disturbance produces a potential (called a **field**) to produce a **force**
    ... thus, the force particle is said to *transmit* a force

- force is *experienced* by a **matter particle** having the appropriate charge
  ... and thus, they are said to *couple*

- when coupling occurs, **radiation** results

Electromagnetic spectrum ... some important additional information

❒ Read: ThoughtTraps 1, "electromagnetic energy" in section on sensation as a building block of consciousness

Modern humans live in a soup of electromagnetic energy ... of both natural and artificial (man-made) origins.

- Our most dominant sense (vision) is based entirely on the ability of our eyes to detect electromagnetic energy patterns in the environment surrounding us.
- Our modern telecommunications are based entirely on electromagnetic energy ... and, because of our heavy reliance on a wide diversity of electronic devices ... we modern humans live in an environment that is thoroughly polluted with electromagnetic energy, much more so than our ancestors ever experienced.

☞ Consult a diagram to familiarize yourself with the visible vs. invisible parts of the spectrum, and the amount of energy associated with the different parts.

Electromagnetic energy has a dual nature: it can radiate (exist) as waves (at one moment) and as particles (at a different moment)

... it is a *vibration of pure energy*

... it travels at a very high speed ("speed of light": about 300,000 km/sec or 186,000 miles/sec)

■ **waves** ... have length and frequency ... both can be measured

	defined as	measured in
• **length**	distance, from crest to crest	nm, cm, m, or km
• **frequency**	number of complete waves (crest to crest, i.e. a cycle) that pass a given point in one second	Hertz ... Hz 1 Hz = one cycle/sec 1 kHz = thousand cycles/sec 1 MHz = million cycles/sec 1 GHz = billion cycles/sec

➜ the longer the wavelength .... the lower the frequency and energy level

➜ the shorter the wavelength .... the higher the frequency and energy level

■ **particles** ... are called photons

The electromagnetic spectrum encompasses all natural and human-made sources of electromagnetic (EM) energy. It is generally shown as frequencies in Hz (often accompanied by wavelengths) ... starting with zero and proceeding from lower frequencies (longer wavelengths) to higher frequencies (shorter wavelengths).

➜ **visible light:** Generally discussed in terms of wavelengths (rather than frequencies), this is the part (400 to 700 nm range) of the spectrum "visible" to humans because our eyes are *sensitive* to these wavelengths (i.e. can detect them).

400 nm range	⇨	700 nm range
violet	⇨	red

These same wavelengths are among those in sunlight that reach the surface of the Earth with greatest intensity.

➜ **non-visible parts** of the spectrum (to either side of visible light):
- *beyond violet* (higher frequency; shorter wavelength): e.g. ultraviolet, cosmic rays, X-rays, gamma waves
- *below red* (lower frequency; longer wavelength): e.g. infrared, radio waves

Some electromagnetic energy is capable of breaking chemical bonds in molecules, i.e. it can create ions ("ionizing").

➜ **ionizing radiation:** beyond violet .... breaks chemical bonds in molecules
➜ **non-ionizing radiation:** visible and below red ..... cannot break chemical bonds

There are diverse human-made sources of electromagnetic radiation in our environment, all associated with our modern, technological world.

➜ **extra low frequency:** ELF	frequencies from zero up to 1000 Hz (1kHz) → main sources: our electrical power supply and all appliances using electricity ... 60 cycles/sec is the frequency of electricity in homes in North America
➜ **very low frequency:** VLF	frequencies from 1 kHz to 500kHz
➜ **intermediate frequency:**	frequencies from 300 Hz to 10 MHz → main sources: computer screens, anti-theft devices, security systems
➜ **radiofrequency:** RF	frequencies of 500 kHz to 500 MHz → main sources: radio, television, radar, cellular telephone antennas
➜ **microwave:**	frequencies from 500 MHz up to visible light → main source: microwaves

Natural sources of electromagnetic radiation in our environment include:

➜ sunlight
➜ solar wind (giving rise to the Northern Lights)
➜ cosmic rays (from outer space)
➜ radioactive decay of elements
➜ Earth's geomagnetic field (spinning core of molten iron)
➜ electrical storms

"Dark energy" in the Universe

☞ under construction

Question: What is dark energy?
Answer:

Standard Model of Physics

Question: What is the "Standard Model of Physics"?

Answer: It is the surprising simple picture, of symmetry and pattern, among the fundamental particles of ordinary matter and their interactions (i.e. how they are held together) by way of 3 of the 4 fundamental energy forces ... in quantum fields.

☞ I.e., the Standard Model is the physical theory that dominates the discipline of high-energy particle physics ... which seeks to understand the fundamental nature of matter.

- Particles fall into two categories:
  1) matter particles: quarks & leptons ... N = 6 of each, for a total of 12
  2) force particles (bosons) of 3 of the 4 fundamental forces ... those three that can be described by quantum theory (gravity, the 4^{th} cannot yet be so described)
     - electromagnetic force
     - strong nuclear force
     - weak nuclear force

☞ The Standard Model is an unfinished theory ... one reason is that it does not yet accommodate the fundamental force of gravity ... nor does it include the poorly understood "dark energy" that cosmologists are now becoming aware of as a major ingredient in the Universe ... nor can it answer the question "why does matter have mass?". The "unified theory" of physics, or "theory of everything" strives to answer all these questions ... but, as of yet, there is no such theory.

A chart (like that below) is generally used to summarize the particles in the Standard Model, as it is currently constructed. Note ... each of the particles has properties of mass (which may be 0) and charge (which may be 0).

	Matter Particles			**Forces**	
	Generation #1	**Generation #2**	**Generation #3**	**Force**	**Particle**
Quarks	• up u	• charm c	• top t	• electromagnetic	photon γ
	• down d	• strange s	• bottom b	• strong nuclear	gluon g
Leptons	• electron e	• muon μ	• tau τ	• weak nuclear	bozon Z
	• electron neutrino v_e	• muon neutrino v_μ	• tau neutrino v_τ	• weak nuclear	bozon W

Overview of some major theories in modern physics

Standard Theory of Physics

- The *Standard Theory of Physics* is the surprising simple picture, of symmetry and pattern, among the fundamental particles of ordinary matter and how they are held together by way of three of the four fundamental energy forces ... in quantum fields. It is an unfinished theory ... as it does not include, for example, gravity or dark energy. Also, it does not answer explain why matter has mass (see Higg's particle below).

General Relativity Theory

- Einstein's theory ... which explains the force of gravity and the nature of space and time. This is not a quantum field theory.

Grand Unification Theory

- the theory, when worked out, that will unite the standard model of physics .. with general relativity.

Higg's Particle

- The Higg's particle is the *hypothesized* carrier of a *hypothesized*, all-pervading fundamental field that endows mass on elementary particles through its interactions with them.

Special Relativity Theory

- Einstein's theory describing the behaviour of things traveling at the speed of light

Theory of Everything

- The *theory of everything* strives to include the *standard model of physics* and answer its unresolved problems ... but, as of yet, there is no such theory that achieves this ... although various efforts exist, including:

    - string theory

CHEMISTRY

☺ ... its Big Questions about Nature

1) What different kinds of atoms (i.e. elements) are there in the Universe?

2) What properties and relationships exist among the different elements?

3) Why do atoms become ions, or come together to form molecules?

4) What happens when particular types of energy conversions occur?

❐ Read: *Integrated Science*
❐ Read: *The Periodic Kingdom*

QUESTION: What different kinds atoms (i.e. elements) are there in the Universe?

The **Periodic Table of the Elements** is an inventory (an all inclusive list) of the different kinds of atoms (which are called ***elements***) that occur in the Universe ... **and it is considered one of the most important concepts in chemistry.** In the words of Atkins (1995):

> The Periodic Table is a remarkable demonstration of the fact that the elements are not a random clutter of entities but instead display trends and lie together in families. An awareness of the Periodic Table is essential to anyone who wishes to disentangle the world and see how it is built up from the fundamental building blocks of chemistry, namely the elements. Anyone who seeks to be familiar with a scientific world view must be aware of the general form of the Periodic Table.
>
> ☞ The *quantization of atomic energy levels* and the *Pauli Exclusion Principle* are the theoretical constructs which explain the Periodic Table of the Elements (see Physics ... structure of the atom).

QUESTION: What is an element?

Answer: Elements are simply the different types of atoms that occur in the Universe.

- remember (from physics) ... an atom is a "piece" of matter that cannot be decomposed via electromagnetic forces into simpler substances (sometimes these forces are referred to as "chemical forces")
- remember (from physics) ... an atom can be decomposed by nuclear forces ... into subatomic particles:
  - leptons ... electrons
  - quarks ... protons and neutrons

QUESTION: How many different elements are there in the Universe?

Answer: There are ***92 naturally occurring elements***, and as many as 24 more that have been created by scientists in the laboratory ... for a present day total of 116. Elements created in a lab are referred to as ***man-made elements***, or *artificial elements*.

QUESTION: What determines the order of the elements in the Periodic Table?

Answer: Elements are placed in the Periodic Table in a particular **order** ... this order is logical, being based on mass (≈weight) from the lightest to the heaviest element. This order corresponds to the ***number of protons*** found in one atom of that element ... and the number of protons, in turn, gives an element's atomic number. Thus, elements are placed in the Table from #1 (hydrogen, H, the lightest) to #116 (the heaviest).

QUESTION: Why is the Periodic Table generally shown in a particular shape (pattern)?

Answer: The Periodic Table is a **patterned arrangement** of the elements that reflects the ***periodic relationship*** of some extremely important properties of the elements.

terminology to describe "parts" of the Table

⇨ consult a copy of the Periodic Table that highlights these different "parts" or areas

- block = s, p, d, or f (hydrogen by itself in no block)
- period = left to right across the Table (same as row)
- row = left to right across the Table
- group = top to bottom in the Table *but for the s and p blocks only*
- column = top to bottom in the Table *for all blocks*

✺ Make sure you understand how these different parts relate to each other.

QUESTION: What symbols are used to represent the elements?

Answer: Each element in the Periodic Table can be represented by a word, or by a symbol.

The symbol for an element ... is generally the capitalized first letter of an element's name ... but, to avoid redundancy (some elements have the same first letter), some deviation from this general approach is found

e.g. the element called .... carbon ..... is represented by the symbol C
the element called .... sulfur ...... is represented by the symbol ..... S
the element called .... sodium ... is represented by the symbol ..... Na

QUESTION: What properties and relationships exist among the different elements?

Answer: several ... as outlined below.

- ***Properties*** are characteristics or traits ... i.e. "things" ... that can be counted or measured about a particular element.
- ***Some important relationships or trends*** can be seen when one compares some of the properties of the different elements.

  The major relationship or trend looked for is "periodicity" which means to recur, to return, or to occur again on a regular or predictable basis ... such that an overall pattern can be seen.

✳ **It is from this overall pattern (of periodic relationships among some of the properties) that the Table gets its name, i.e. the Periodic Table of the Elements.**

Different properties of the elements

Elements have a variety of properties ... which can be viewed from different perspectives and then classified or grouped* as:

1) "things" about one atom of the element, and that focus on the atom as a level of organization in the Universe
   → ***atomic properties***

2) "things" about an element related to changes that do or do not involve changing its electron configuration (i.e. make-up)
   → ***chemical properties*** .... are "things" about an element related to changes in its identity or make-up (in terms of electron configuration) ... that occur when it seeks "stability", i.e. *becomes* an ion or part of a molecule

   → ***physical properties*** .... are "things" about an element related to changes that do not involve changes in its electron configuration

3) "things" about elements that do or do not recur, in a regular or predictable pattern, when different elements are compared
   → ***periodic*** .... are "things" the do recur in a predictable pattern, when different elements are compared

   → ***non-periodic*** .... "things" that do not recur in a predictable pattern, when different elements are compared

Atomic properties

- are "things" about <u>one</u> atom ... of a particular element
- includes:
  - **atomic number** .... the *number of protons* .... in one atom
  - **atomic mass** .... the *number of protons PLUS neutrons* .... in one atom
  - **electron configuration** .... the *numbers and locations of the electrons* .. in one atom

e.g. the element carbon has an atomic number of 6 and an atomic mass of 12
... information which chemists write in a standard form* as:

$$^{12}_{6}\mathrm{C}$$

<u>note</u>
- atomic mass .... is written to the .... upper left .... as a superscript
- atomic number ..... is written to the .... lower left .... as a subscript

■ *atomic number*

= the *number of protons* in one atom
- an element's atomic number <u>never changes</u>
  → because an element <u>cannot</u> gain or lose protons ... it has <u>an exact number</u> of protons which never changes

■ *atomic mass*

= the average mass (weight) of the various forms (isotopes) of an element ... based on the collective mass (weight) of the protons and neutrons ... which each count as "1"
  → basically, therefore, atomic mass = the *number of protons PLUS neutrons* in one atom

<u>isotopes</u>
= the various forms that one particular element can take ... because:
→ different atoms of the same element can have *different numbers of neutrons*

e.g. the element carbon has three isotopes, with ^{12}C being the most abundant

$$^{12}_{6}\mathrm{C} \qquad ^{13}_{6}\mathrm{C} \qquad ^{14}_{6}\mathrm{C}$$

... in this example, ^{12}C has 6 neutrons, ^{13}C has 7 neutrons, and ^{14}C has 8 neutrons
✳ note: the number of protons <u>does not</u> change from one isotope to the next

■ *electrical balance ... of an atom*

- in an **electrically balanced atom ...**

  ... the numbers of protons <u>exactly equal</u> the numbers of electrons

  e.g. in carbon .... there are ..... 6 protons .... and .... 6 electrons
  chlorine ...... there are .....17 protons .... and ..... 17 electrons

→ but, not atoms are not always balanced ... because <u>electrons</u> can be gained or lost
... electrically unbalanced atoms are called **ions**

<u>ions</u>

see: section on "chemical properties" of an atom

■ *electron configuration ... of an atom*

☺ various concepts (parts) must first be understood, before "electron configuration" (the WHOLE) can be understood ... ***it requires that YOU connect the dots to see the pattern!***

parts **---→** **WHOLE**

parts	WHOLE
• electrically balanced atom of an element • number of electrons in one atom	electron configuration

• orbitals

  • different types of orbitals
  • number of electrons in each orbital

• energy levels
  • different energy levels
  • types of orbitals at each energy level
  • maximum number of electrons in orbitals of each energy level

• pattern of how the electrons fill the orbitals

• each element has its own (i.e. defining) electron configuration

electron configuration ... of an atom (continued)

orbitals

- all electrons ... move continuously ... and the 3-D locations defined by their "flight paths" are called **orbitals**
  - → orbitals are centred ... on the nucleus of the atom
  - ⊎ an orbital ... is like a cloud, and the electrons will always be found somewhere within

- orbitals come in four different types ... as determined by their shape:

type of orbital	shape of this type of orbital
s	spherical .... ○
p	dumbbell ...... ∞
d	too complex to describe in words, or to draw
f	too complex to describe in words, or to draw

- each orbitals can have one, or a maximum of two, electrons

energy levels

- orbitals are found at different **energy levels** (shells)
  - different energy levels occur at different distances from the atom's nucleus
    ... with those closer to the nucleus ... having less energy associated with the electrons
    - → the different energy levels are often drawn as concentric circles around the nucleus
      ... and the closer an energy level is to the nucleus, the less energy associated with the electrons in its orbitals

→ **energy levels are labeled** with letters or numbers ... starting closest to the nucleus.
... and only specific types of orbitals can occur at each level, as shown in the pattern below

letter		number	orbital types found at this level			
K	or	1	s			
L	or	2	s	p		
M	or	3	s	p	d	
N	or	4	s	p	d	f
		5	s	p	d	f
		6	s	p	d	
		7	s	p		
		8	s			

→ at an energy level, there are maximum numbers of each type of orbital ... these are:

type of orbital	maximum number	***when all these orbitals are filled ... the maximum, total number of electrons** ... in these orbitals is*
s	1	1 x 2 = **2**
p	3	3 x 2 = **6**
d	5	5 x 2 = **10**
f	7	7 x 2 = **14**

<u>the order ... in which the electrons fill the orbitals of the energy levels</u> **... follows a pattern:**

level	orbitals
1	s
2	s p
3	s p d
4	s p d f
5	s p d f
6	s p d
7	s p
8	s

... and thus ... the resulting **electron configuration** for an atom of an element ... which is written in a particular way

electron configuration ... some examples

element	atomic number	# of electrons	electronic configuration
hydrogen	1	1	$1s^1$
helium	2	2	$1s^2$
lithium	3	3	$1s^2 2s^1$
beryllium	4	4	$1s^2 2s^2$
boron	5	5	$1s^2 2s^2 2p^1$
carbon	6	6	$1s^2 2s^2 2p^2$
nitrogen	7	7	$1s^2 2s^2 2p^3$
oxygen	8	8	$1s^2 2s^2 2p^4$
fluorine	9	9	$1s^2 2s^2 2p^5$
neon	10	10	$1s^2 2s^2 2p^6$
sodium	11	11	$1s^2 2s^2 2p^2 3s^1$
magnesium	12	12	$1s^2 2s^2 2p^2 3s^2$
aluminum	13	13	$1s^2 2s^2 2p^2 3s^2 3p^1$
silicon	14	14	$1s^2 2s^2 2p^2 3s^2 3p^2$
phosphorus	15	15	$1s^2 2s^2 2p^2 3s^2 3p^3$
sulfur	16	16	$1s^2 2s^2 2p^2 3s^2 3p^4$
chlorine	17	17	$1s^2 2s^2 2p^6 3s^2 3p^5$
argon	18	18	$1s^2 2s^2 2p^2 3s^2 3p^6$
potassium	19	19	$1s^2 2s^2 2p^2 3s^2 3p^6 4s^1$

Do you see the pattern developing?

Chemical properties

- are "things" about an atom ... that change or react when it forms into an ion or becomes part of a molecule

- Chemical properties exist because of the different electron configurations of atoms of the different elements.

■ ***electronegativity***

... how "greedy" an atom is to obtain more electrons

■ ***energy of ionization***

... how strongly an atom "holds onto" its electrons ... i.e., how much energy would be required to remove its electrons, or how much energy is required to make in an ion

■ ***oxidation state***

■ ***electron affinity***

ions

✴ arising from the chemical properties of an atom ... is the following possible *modified form* of an atom:

- ion: an electrically unbalanced atom (general term)
  ...i.e. an electrically charged atom

☞ see later section on "ions"

☹ do not confuse *ions* and *isotopes*

Physical properties

- are "things" about an element <u>not</u> related to changes in identity or make-up (those are chemical properties that occur when an atom becomes an ion or part of a molecule)
- the *atomic properties* identified earlier ... can also be considered to be physical properties
- also includes:
  - atomic radii
  - enthalpy of atomization
  - enthalpy of vaporization
  - enthalpy of fusion
  - molar volume
  - density
  - boiling point
  - melting point
  - thermal conductivity

✳ remember, matter itself always assumes a particular physical state ... the possibilities are:
  - plasma, gas, liquid, solid

<u>Periodic properties</u>

- are "things" that recur, in a regular or predictable pattern, when different elements are compared

  • **"periodic"** means to recur, to return, or to occur again ... on a predictable or regular basis

- the pattern of the Periodic Table is based on the ***periodic properties*** among elements ... the information or trends that you should be able to "get" from the pattern of the Periodic Table include:
  - atomic number and mass
  - type of element:
    - metal ... and what kind
    - non-metal ... and what kind
    - Noble gas
    - hydrogen
  - last electrons acquired, as orbitals fill
    - s block
    - p block
    - d block
    - f block
  - electronegativity trend: ↑ left to right ↓ top to bottom
  - energy of ionization trend: ↑ left to right ↓ top to bottom (f block with slight variation)
  - atomic radii (size) trend: ↓ left to right ↑ top to botton
  - oxidation states
  - electron affinity

<u>Non-periodic properties</u>

- are "things" that do <u>not</u> recur in a predictable pattern, when different elements are compared

- includes ... the physical properties ... except:

  ✳ *atomic radius*
  → which is a periodic property

  ✳ *electronic configuration*
  → where the pattern of filling the orbitals for the different elements has a recurring aspect to it, as well as growth and symmetry

Models for atoms

Western science makes extensive use of “models” to represent “real things” in the Universe. A drawing or picture is a type of model.

Two types of models are commonly used to represent atoms:
- the Bohr model
- the fly-speck model

Bohr model

- This model shows all the electrons in all energy levels of one atom of the element.

→ a large dot .... represents ..... the nucleus
→ circles .... represent ...... the energy levels
→ dots .... represent ...... the electrons

examples
you provide them

fly speck model

The name “fly-speck” is a ⊎ .
The more technical name is “Lewis electron dot symbol”, or “Lewis symbol”.

- This model shows only the electrons in the outermost energy level of one atom of the element.

→ the element’s symbol .... represents ..... the nucleus
→ dots .... represent .... the electrons of the outermost energy level

examples
you provide them

QUESTION: Why do atoms become ions, or come together to form molecules?

Answer: to satisfy their craving for "stability".

Stability

The concept of stability is based on an atom's electronic configuration ... in particular, on the "s" and "p" electrons in the outermost energy level.

The s and p electrons determine how the atom will change or react to achieve "stability" ... which is a state that an atom "craves" to reach or become.

Stability is defined as "a full outermost energy level" ... of s and p electrons.

- "full" means "s^2 and p^6" ... as in:
  - $1s^2$ .... and leads to the ..... Exception of 2 [to the Rule of 8]
  - $2s^22p^6$ .... and leads to the ..... ***Rule of 8***
  - $3s^23p^6$ .... and leads to the ..... ***Rule of 8***

To achieve "stability" ... atoms will lose or gain electrons.

✳ This gain or loss can occur such that:

1) an **ion** forms

2) a **molecule** forms ... and is called:
   - **organic** ...... if it contains carbon [with the exception of CO_2 ... which is considered inorganic]
   - **inorganic** ... if it does <u>not</u> contain carbon

Ions

- may be a:
  - **simple ion** .... a charged atom by itself, or
  - **complex ion** .... a charged combination of atoms
- **cations** .... those which have formed by losing electrons .... become positively charged
  → a "loss of electrons" ... is referred to as **reduction**
- **anions** .... those which have formed by gaining electrons .... become negatively charged
  → a "gain of electrons" ... is referred to as **oxidation**

▪ common cations

you fill in:
Column / Row (of element)

1+ cations

- H^+ .... hydrogen (also a proton)
- Li^+ .... lithium
- Na^+ .... sodium
- K^+ .... potassium
- Cu^+ .... copper I or cuprous
- Ag^+ .... silver
- Cs^+ .... cesium
- NH^+ .... ammonium

2+ cations

- Mg^{++} .... magnesium
- Ca^{++} .... calcium
- Cr^{++} .... chromium II or chromous
- Mn^{++} .... manganese II or manganous
- Fe^{++} .... iron II or ferrous
- Co^{++} .... cobalt II or cobaltous
- Ni^{++} .... nickle
- Cu^{++} .... copper II or cupric
- Zn^{++} .... zinc
- Sr^{++} .... strontium
- Cd^{++} .... cadmium
- Sn^{++} .... tin II or stannous
- Ba^{++} .... barium
- Hg^{++} .... mercury I or mercurous / mercury II or mercuric
- Pb^{++} .... lead II or plumbous

→ it would be most common to write these cations as, e.g., Mg^{2+} rather than Mg^{++}

3+ cations

- Al^{+++} .... aluminum
- Cr^{+++} .... chromium III or chromic
- Fe^{+++} .... iron III or ferric

→ it would be most common to write these cations as, e.g., Al^{3+} rather than Al^{+++}

▪ common anions

1- anions

- $C_2H_3O_2^-$ ..... acetate
- Br^- ..... bromide
- ClO_3^- ..... chlorate
- Cl^- ..... chloride
- CN^- ..... cyanide
- $H_2PO_4^-$ ..... dihydrogen phosphate
- Fl^- ..... floride
- H^- ..... hydride
- HCO_3^- ..... hydrogen carbonate or bicarbonate
- HSO_3^- ..... hydrogen sulfite or bisulfite
- OH^- ..... hydroxide
- I^- ..... iodide
- NO_3^- ..... nitrate
- NO_2^- ..... nitrite
- ClO_4^- ..... perchlorate
- MnO_4^- ..... permanganate
- SCN^- ..... thiocyanate

2- anions

- CO_3^{--} ..... carbonate
- CrO_4^{--} ..... chromate
- $Cr_2O_7^{--}$ ..... dichromate
- HPO_4^{--} ..... hydrogen phosphate
- O^{--} ..... oxide
- O_2^{--} ..... peroxide
- SO_4^{--} ..... sulfate
- S^{--} ..... sulfide
- SO_3^{--} ..... sulfite

→ it would be most common to write these anions as, e.g., $(SO_4)^{2-}$ rather than SO_4^{--}

3- anions

- AsO_4^{---} ..... arsenate
- PO_4^{---} ..... phosphate

→ it would be most common to write these anions as, e.g., $(PO_4)^{3-}$ rather than PO_4^{---}

4- anion

- SiO_4^{----} ..... silicate: simple ion or orthosilicate .... = **silicate tetrahedron** *

* the silicate tetrahedron is very important in geology ... as a "building block" for many minerals ... it would generally be written as $(SiO_4)^{4-}$ rather than SiO_4^{----}

▪ hydrogen ion and pH

- The H atom, *in its most common isotope*, consists of one proton and one electron. Thus, when it loses its electron ...i.e. when it becomes an ion ... it is just a lone proton.

- the **hydrogen ion** (a lone proton) is generally symbolized as: $\mathbf{H^+}$

- The concentration of H^+ in a liquid medium is referred to as the **pH** of that medium ...

  ... and it is indicated as a number using the formula: $pH = -\log [H^+]$

  ... which is read as: pH = the negative logarithm of the concentration of protons

- The **pH scale** runs from 0 to 14 (or 16) ... with 7 as the <u>neutral point</u>.

  → **neutral pH** is based on the numbers of protons in a litre of pure water ... i.e. the concentration of H^+

  → in a litre of pure water ... there is one proton for every 10,000,000 water molecules

  - this is 1/10,000,000 ... which can be written as: 10^{-7}
  - the negative logarithm of 10^{-7} is 7 ... thus giving 7 as neutral pH

  → anything below pH 7 on the scale is referred to as **acidic**
  → anything above pH 7 on the scale is referred to as **basic** (or alkaline)

  → the pH scale is a **logarithmic scale** ... which means that between each full unit in the scale there is a change of X10 (not +10).

  - examples:
    - between pH 3 and pH 4 ... there is a 10X difference in H^+ concentration
    - between pH 3 and pH 5 ... there is a 100X difference in H^+ concentration
    - between pH 3 and pH 8 ... there is a 10,000X difference in H^+ concentration

- The normal pH of your blood is about 7.2 ... and if that changes ... you will die! Thus, it is critical that pH be maintained at a constant level.

  This is achieved, in living organisms, by **buffer systems** that act “like a sponge” ... removing H^+ when there are too many (“soaking them up with the sponge”), and adding H^+ when there are not enough (“squeezing the sponge to release them”).

Molecules

- ***are combinations of atoms*** ... in which **pairs of electrons** are shared among the different atoms such that each atom is satisfied

e.g. $C_6H_{12}O_6$ .... is the glucose molecule
H_2O .... is the water molecule
CH_4 .... is the methane molecule

→ these molecules are written in their **molecular formula**
☞ do not confuse *molecular formula* with *molecular structure*

■ chemical bonds

- a chemical bond is defined as .... a pair of electrons
- a chemical bond is symbolized .... as a short line in a model for the molecule ... called a **molecular structure**

examples

- water

- methane

- glucose

Question: Are there different types of chemical bonds?

Answer: Yes, there are different types of chemical bonds, based on how "equal" this sharing is.

- the different types of chemical bonds:

• **covalent** .... electrons are shared .... equally

• **polar** .... electrons are shared .... very unequally

• **ionic** .... electrons are not shared .... stolen

QUESTION: What happens when particular types of energy conversions occur?

Answer: In answering the above question, it must first be understood that the four fundamental forces of energy in the Universe cannot, *given the normal environmental conditions on our Earth*, be converted (changed) from one into another ... which is why they are called "fundamental". Particular energy conversions can, however, occur within each fundamental force ... with very specific significances and outcomes (as discussed below).

Electromagnetic energy

Electromagnetism ... is the force which makes modern civilization possible: it lights up our cities and runs our household appliances, computers, telephones, and other electrical equipment. Without this force and our human mastery of it, including our ability to **convert** (change or transform) it into different subforms ... we would be living in a world lit by candles and fires.

☞ Conversion is always from a higher quality form of energy ... to a lower quality form.. I.e., all energy conversions are (overall) downhill ... and generally involve energy lost as **heat**.

☞ Different forms of the electromagnetic force include, for example:
- chemical energy
- visible and non-visible light (❖ **the electromagnetic spectrum**)
- electricity

☞ Recall ... the particle associated with the electromagnetic force is the **photon**.

☞ The energies available to an atom depend directly on the electromagnetic force between the nucleus and the electrons. And, the difference in energy between energy levels in an atom corresponds to a specific wavelength of electromagnetic energy.

- When the atom encounters a photon of this specific wavelength, the photon will be absorbed by the atom ... and the electron will "jump"from the lower energy level to the higher one ... becoming a so-called "excited electron".
- When the electron falls back down to its original state, the atom emits a photon of this same specific wavelength.

→ Thus, only certain photons can be absorbed or emitted by an atom.

☞ Our human bodies are powered by the "chemical energy" in the food we eat.

... the collection of all the energy conversions going on in an individual living organism is referred to as **metabolism** ... and each conversion takes places within the context of a **chemical reactions involving molecules**

• chemical reactions ... can result in the:

- "building" or "synthesis" of new molecules

→ these types of chemical reactions .... are called: **anabolic**

- "break down" molecules

→ these types of chemical reactions .... are called: **catabolic**

... "**glucose catabolism**" in our bodies involves the chemical energy of the chemical bonds in the glucose molecule (the universal food molecule) ... being converted into new chemical bonds in a molecule called ATP (the energy currency molecule) ... whose energy is then used to pay almost all "energy debts" in the cells that make up our tissues, organs, and bodies

→ the overall process by which ATP is synthesized is called **cellular respiration**

→ the entry of glucose into the cells ... from the bloodstream ... is regulated by the hormone insulin

Strong nuclear energy

Strong nuclear energy ... is the force that holds the quarks in the nucleus of an atom together.

... and, the scientific investigation of it is part of "nuclear chemistry" ... which is the study of changes in matter originating in the nucleus of the atom.

☞ It is possible to split a nucleus apart ... i.e., to have "**nuclear fission**" occur ... and the result will be two major fragments and the ejection of one or more neutrons
❖

☞ It is possible to form a new nucleus ... i.e., to have "**nuclear fusion**" occur ... via the combination of two or more lower mass nuclei ... this forms the new, heavier mass nucleus and also results in the ejection of neutrons, protons, photons, and/or alpha particles.
❖

✳ **Nuclear fusion occurs in our Sun ... as hydrogen fuses ("burns") to produce helium.**
❖

- The photons (particles of electromagnetic energy) that are ejected ... as a result of nuclear fusion occurring in our Sun ... form the basis for life on Earth.

  → green plants are capable of capturing the Sun's energy (i.e., the photons) ... and using it as the energy source required to synthesize glucose molecules

  → the overall process by which plants do this is called **photosynthesis**

<u>Weak nuclear force</u>

Weak nuclear energy ... is the force that can change an up quark into a down quark, and vice versa.

<u>Radioactive decay</u>

Conversions of energy ... are responsible for "radioactive decay" of atomic nuclei.
- strong nuclear energy is responsible for α decay (alpha decay)
- weak nuclear energy is responsible for β decay (beta decay)
- electromagnetic energy is responsible for γ decay (gamma decay)

... The investigation of radioactive decay is part of "nuclear chemistry" ... which is the study of changes in <u>matter</u> originating in the <u>nucleus</u> of the atom.

☞ The <u>nuclei</u> of some atoms have an **unstable** arrangement of protons and neutrons ... and, in seeking to arrive at a stable arrangement ... will undergo **radioactive decay** ... which involves changes in the nucleus.

- as the nucleus changes, it emits (gives out, allows to escape) **<u>energy</u>** as **radiation** or **radioactive rays** ... in the form of what are called "**particles**"

- unstable nuclei are said to be **radioactive**

  → The radioactive properties of the nucleus are essentially independent of the state of the chemical combination of the atom ... thus, it is not important whether it is just an elemental form of the atom, or a compound (in a molecule) form.

- **stable** vs. **unstable**

  Question: What is considered "stable" vs. "unstable"?

  Answer: There is no single rule that can be applied, however ... the overall pattern is:
  - for elements with low numbers of protons (up to about 20) ...
    → "stable" is roughly the same number of protons and neutrons
    → "unstable" is any other arrangement
    e.g. carbon's most common isotope (^{12}C) ..... has 6 and 6 ... and is stable
    carbon's rarer isotope (^{14}C) .... has 6 and 8 ... and is unstable

  - for elements with large numbers of protons ...
    → "stable" is many more neutrons than protons
    e.g. lead's isotope (^{208}Pb) ...... has 126 neutrons and 82 protons .....and is stable

- all nuclei with 84 or more protons are radioactive (atomic number is, or is greater than, 84)
- decays occur randomly in time ... but large collections of radioactive materials containing a particular element have a predictable "average lifetime" or "half life'
  - → this predictability forms the basis of "carbon dating"

☞ there are three common types of radioactive decay ... named after the first three letters of the Greek alphabet
- α (alpha)
- β (beta)
- γ (gamma)

→ the first two types of decay involve one element changing into another element ...
... a process called **transmutation**

1) α decay (= alpha decay)

- produces very weak radiation
  ☹ this radiation is stopped by skin, but is not too dangerous unless it somehow enters the deeper body
  ... this radiation can be stopped by a sheet of paper

⇨ can be understood in terms of **strong nuclear energy** interactions

- emits an "α particle"
  ... this particle = helium (He) nucleus ... which is symbolized: ^{4}He

  ❖ you draw it

- changes the parent atom .... as follows:
  - atomic mass ↓ by 4 [4 = 2 fewer protons and 2 fewer neutrons]
  - atomic number ↓ by 2 [2 fewer protons]

- examples:

a) $^{238}U \rightarrow {}^{234}Th$ + the emitted ^{4}He

❖

b) $^{226}Ra \rightarrow {}^{222}Rn$ + the emitted ^{4}He

❖

2) β decay (= beta decay)

- produces stronger radiation than alpha decay
  ☹ this radiation will penetrate about 1 cm below the surface of the skin, but is not too dangerous unless it somehow enters the deeper body
  ... this radiation can be stopped by a 6 mm thick sheet of aluminum

⇨ can be understood in terms of **weak nuclear energy** interactions

- emits the "β particle" which can be either of two types of particles ... depending on which one of two sub-types of decay has occurred
  • β minus decay .... emits an electron ...... symbolized: e^-
  • β plus decay .... emits a positron .... symbolized: e^+

β minus decay (electron emission) .... changes the parent atom as follows:
  • atomic mass stays the same [same = changes cancel each other]
  • atomic number ↑ by 1 [1 more proton]

- example: $^{14}_{6}C \rightarrow {}^{14}_{7}N$ + the emitted e^- and an antineutrino

via: a neutron .... changing into .... a proton ..... **PLUS** emission of : e^- + antineutrino
  ... the change involves weak nuclear forces ... W bozons
  ... the antineutrino is symbolized: v with a bar over it

❖ draw: a neutron changing into a proton ... with an e^- + antineutrino escaping

✳ the process of **inverse beta decay** involves the capture, by the *nucleus*, of an inner-shell electron from the surrounding electron cloud, and the emission of a neutrino

via: a proton changing into a neutron .... with a neutrino escaping

β plus decay (= positron emission) .... changes the parent atom as follows:
  • atomic mass stays the same [same = changes cancel each other]
  • atomic number ↓ by 1 [1 fewer proton]

- example: $^{18}_{9}F \rightarrow {}^{18}_{8}O$ + the emitted e^+ and a neutrino

via: a proton ..... changing into .... a neutron ... **PLUS** emission of: e^+ + neutrino
  ... the change involves weak nuclear forces ... W bozons
  ... the neutrino is symbolized: v

❖ draw: a proton changing into a neutron ... with a e^+ + neutrino escaping

3) γ decay (= gamma decay)

- produces very strong radiation
  ☹ this radiation penetrates human tissues and organs very easily, and can be very dangerous
  ... this radiation can be blocked by thick layers of lead

⇨ can be understood in terms of **electromagnetic energy** interactions

- emits one or more high energy photons (γ rays) ... from an "excited nucleus"

→ an *excited nucleus* ... is:
- a nucleus with an abnormally high amount of energy
- symbolized, e.g. C*

- changes the parent atom .... to a lower energy state
  - atomic mass stays the same
  - atomic number stays the same

- example: $^{12}C^* \rightarrow {}^{12}C$ **+ the emitted γ**

❖

✳ gamma decay does not modify the chemical properties of the daughter atom ... unlike the other two types of decay, which do ...
... because they involve transmutation (changing into a different element) ...
... and thus, obviously a daughter with different chemical properties than the parent

✳ a gamma (γ) ray ... is a particular energy level of photon = γ particle
- recall, photons are the particles of electromagnetic energy
- e.g. in the electromagnetic spectrum ... as emitted by the sun ... there are:
  - gamma rays
  - X-rays
  - visible light
  - etc

❖ consult a diagram showing the ***electromagnetic spectrum***

Carbon dating

see inserts

GEOLOGY

☺ ... its Big Questions about Nature

1) How is the matter of the Universe arranged in planet Earth?
2) What are the Earth's building blocks?
3) What are minerals? How do they originate?
4) What are rocks? How do they originate?
5) How do continents form? ... Plate Tectonics Theory

❒ Read: *The Last Billion Years; a Geological History of the Maritime Provinces of Canada*
❒ Read: *Integrated Science*

QUESTION: How is the matter of the Universe arranged in the planet Earth?

Earth ... model of ... showing the various "layers" ... from outermost to innermost:

- crust
  - continental crust ..... up to 20-70 km thick
  - oceanic crust .... up to 4-7 km thick

- upper mantle .... extends to 660 km in depth
- lower mantle .... extends from 660 to 2900 km in depth

- outer core .... extends from 2900 to 5150 km in depth
- inner core .... extends from 5150 km to the centre of the Earth at 6370 km

❖ consult a diagram ... to better understand these different layers and their relationships
☺ make the pattern "talk to you"

Question: What properties characterize the different layers?
Answer:

- crust .... cool, hard, strong

- lithosphere .... cool, hard, strong

----

- mantle
  - upper
    - → upper most .... included in lithosphere (... cool, hard, strong)
    - → asthenosphere .... hot, weak, plastic
    - → remainder of upper .... hot, under great pressure, mechanically strong but plastic
  - lower .... high pressure, semi-liquid

----

- outer core .... semi-liquid to solid
- inner core .... solid

Question: What is the **lithosphere**?
Answer: a zone that includes both the crust and the uppermost mantle ... and which is cool, hard, and strong rock ... it is the “rock zone”.

Question: What is the **asthenosphere**?
Answer: the zone where the hard rock of the lithosphere turns into hot, weak, and plastic matter ... this change in rock properties occurs over only a few km ... and is caused by the Earth’s rising temperature accompanying increasing depth ... 1-2% of the asthenosphere is molten

Question: Why does the remainder of the upper mantle become “mechanically strong” after the asthenosphere, which is weak and plastic?
Answer: the increasing pressure overwhelms the effect of rising temperature ... and the strength of the material increases ... but remains plastic

Question: What elements are most common ... in the different layers?
Answer:

- crust: the eight most abundant elements, in order, are:
  - oxygen
  - silicon
  - aluminum
  - iron
  - calcium
  - sodium
  - potassium
  - magnesium

- core: consists mainly of Fe, with a few % Ni ... and possibly 10% H or Si

Question: What is **magma**?
Answer: magma is molten (melted) rock generated in the Earth

- the inner Earth is a "heat machine" ... it melts its insides

Question: Where does the intense "**heat**" in the inner Earth come from?
Answer: from "residual heat" and the energy released as a result of radioactive decay of elements

→ the temperature of the Earth's core is about 6000°C ... which is about the same as the surface of the Sun

Question: What is **residual heat**?
Answer: It is the heat "left over" from the time of the primordial (very, very young) Earth ... both ... as it formed from a colliding masses of dust and gas particles which heated up as they collided ... and, from the asteroids, comets, and other cosmic debris that crashed into its surface.

→ this heat drives the Earth's "engine" ... causing earthquakes, volcanic eruptions, mountain building, and continual movement of the upper-most, extremely large "chunks" of crust (tectonic plates) sitting on convection cells of mantle rock

QUESTION: What are the Earth's building blocks?

Answer: minerals

QUESTION: What are minerals? How do they originate?

Question: What is a mineral?

Answer:
A mineral is .... a naturally-occurring inorganic material that has:
- a fairly definite *chemical composition* (which is either fixed or varies within a defined range), and
- characteristic *physical properties* that are derived from its molecular structure.

■ chemical composition of minerals
... "chemical composition" refers to the combined answer to two questions:
1) what elements are present?
2) in what combinations are these elements present?

• **as a result of their chemical composition ...
minerals can be categorized as "native" or "non-native"**
... the categories are based on *how many different types of elements* are contained
... another way of stating this is: minerals are classified by their chemical composition
... examples:
☞ native ... contain only one element ... and only one atom of this element
- gold, Au
- copper, Cu
- sulphur, S

☞ non-native ... contain more than one element ... and may have more than one atom of each element
- quartz, SiO_2
→ thus, *non-native* minerals ... are compounds ... that contain ions ... both a *cation* and an *anion*. As a result of containing these ions, two additional concepts emerge for non-native minerals:
• ionic charge
• ionic substitution

✳ *non-native* minerals ... are classified based on the type of ***anion*** they contain.

- simple anion (one element):
  - oxide .... O^{2-}

- complex anion (more than one element):
  - silicate .... $(SiO_4)^{4-}$ .... shape = a tetrahedron, △
  - carbonate .... $(CO_3)^{2-}$

■ molecular structure of minerals

... "molecular structure" is a concept that applies to the <u>non-native minerals</u> ... it is the answer to the question "how are the anions and cations combined?"

• **<u>as a result of their molecular structure ...</u>**
<u>minerals can be categorized as "non-crystalline" or "crystalline"</u>

... these two categories are based on *molecular structure* ... which itself is reflected in the surface of the **breakage pattern** that appears when the mineral is broken

☞ <u>non-crystalline</u> .... breakage pattern = "fracture" .... irregular surfaces

☞ <u>crystalline</u> .... breakage pattern = "cleavage" .... flat surfaces

• **<u>crystalline minerals</u>:** ... the order (i.e. **regular and repeated pattern**) of arrangement of the ions with respect to each other ... leads to the *concept* of:

→ <u>unit cell</u>: the structural combination of ions (i.e. unit or module) that repeats, within the pattern ... and that still has all of the properties of the mineral

other concepts for crystalline minerals:

→ <u>crystallization</u>: freezing point ... i.e. the point at which the liquid state of the mineral turns to the solid state ... i.e., ***crystallization is a cooling down process***

→ <u>crystal face</u>: the planar surface (a surface "as a plane") that develops if crystallization occurs freely in an uncrowded environment

☞ ***crystallization*** of the different minerals (from magma) occurs in a sequence of stages ... a "series" ... between 1200° and 600° C.

❖ consult a diagram or a figure which shows "Order of Crystallization" ... the figure will probably be called "Bowen's Reaction Series"

☺ *make the <u>pattern</u> shown in the figure "talk to you"* ... such that the information you come to understand is:

PATTERN: upon cooling ... those minerals with the highest <u>freezing point</u> crystallize first, and those with lower freezing points later

→ first olivine
→ then pyroxene
→ then hornblende
→ then orthoclase
→ near the end quartz

• definition of crystallization: from the liquid state (= molten) to the solid state

■ <u>physical properties of minerals</u>

NOTE: some properties are *diagnostic*, others are *accessory*

- diagnostic = tells you what mineral is present
- accessory = tells you some other information

- the different properties are:

  → <u>hardness</u> ... and "Mohs' Scale"

  → <u>luster</u> ... and metallic vs. non-metallic

  → <u>color</u>

  → <u>streak</u>

  → <u>cleavage</u>

  → <u>fracture</u>

Cleavage or ***fracture*** ... are terms used to describe how a mineral breaks apart ... and, this is determined by way of a <u>physical experiment</u> ... "hammer it"... i.e. you cannot tell which (cleavage or fracture) just by looking at the mineral.

- cleavage ... shattering is along a regular <u>plane</u> ... determined by the weak bonding of *van der Waals forces*

- fracture ... shattering is irregular ... *isodesmic:* equally strong in all directions (no weak bonding ... no planes)

QUESTION: What are rocks? How do they originate?

Question: What are rocks?

Answer:

A rock is ... composed of two entities:

1) *minerals*
2) *texture*

☞ thus, the definition of a .... **rock = minerals + texture**

And, for any rock, one can ask two very important questions:

1) minerals ... what kind does this rock contain?
2) texture ... how do these minerals fit together (crystal sizes, shapes, and boundary relationships of the minerals contained) in this rock?

✳ **Use the definition, and the answers to these two questions, to frame your BIG PICTURE understanding of all the details about rocks that will be discussed.**

☺ It took geologists a long period of time to understand rocks, ***within the context of the answers to these two questions***.

• petrology = the study of rocks

• **rocks** have distribution in *space* and *time*
... and, a *geological map* provides information about these distributions

☞ The distributions of rocks ... as found in Nature (and as shown on geological maps) are not haphazard. Rather, there are ***scientific reasons*** (i.e. reasons that logical thinking can determine) why particular types of rocks are found in particular locations.

• **rocks** are classified into categories ... of which there are three:

1) igneous
2) sedimentary
3) metamorphic

☞ The classification of rocks is based on how they form (i.e. on their **origin**) ... and thus, an understanding of the **rock cycle** is very important.

■ physical properties of rocks

→ texture: refers to
 1) the size of the mineral crystals contained,
 2) the variation observed in the sizes of the crystals contained, and
 3) the inter-relationship of these two.

→ grain ...of the crystals within the rock:
- fine grained: ≈1 mm
- coarse grained: ≈ 3 cm

 → phenocryst: crystals that can be seen with the naked eye

 → cryptocryst: crystals that cannot be seen with the naked eye

■ chemical properties of rocks

• **mineral discriminators ... for different types of rocks**

... as for example, in igneous rocks:
- quartz is a ***discriminator mineral*** for the families
- orthoclase (OR) is also a ***discriminator mineral***

• **rock-forming minerals**

☞ There are nine ***rock-forming minerals*** that are basic for understanding most rocks.

Why **nine**? It is because these nine are the most common minerals in the crust and mantle. These nine rock-forming minerals are:

Silicates ... all (except quartz) have ... the silicate tetrahedron: $(SiO_4)^{4-}$ ... a complex anion
1. olivine
2. pyroxene
3. amphibole
4. mica ... two: biotite & muscovite
5. clay minerals
6. feldspar ... two: orthoclase & plagioclase
7. quartz ... made up of SiO_2 (silicon dioxide) ... with O^{2-} ... the simple anion

Carbonates ... all have the complex carbonate anion: $(CO_3)^{2-}$

8. calcite
9. dolomite

☞ there are lots and lots of additional rock-forming minerals ... as, for example:
 - pyrite .... a sulphur-bearing mineral

- hematite .... an iron ore mineral

<u>Different varieties</u> of ***feldspar*** exist ... and are given names.

☞ The name is based on the **PATTERN** of content of ... potassium (K), <u>or</u> a mixture of sodium (Na) and calcium (Ca).

1) a pattern of K content .... **orthoclase**

2) a pattern of Na and/or Ca content .... **plagioclase**

There are ***five classes of rock-forming silicates***.

☞ The classification is based on the **PATTERN** of tetrahedral arrangement and relationship

1) independent (= nesosilicate)
   - no shared oxygens
   - e.g. olivine

2) single-chains (= inosilicate)
   - each △ shares oxygens with 2 neighbouring △
   - e.g. pyroxenes

3) double-chains (= inosilicate double-chains)
   - two single chains cross-linked by sharing additional oxygens
   - e.g. amphiboles ... hornblende is the most common type

4) sheets (= phyllosilicates)
   - each △ shares oxygens with 3 others in the same plane
   - e.g. micas, clay

5) frameworks (= tektosilicates)
   - each △ shares all four of its oxygens with neighbouring △
   - e.g. feldspar, quartz

Rock cycle

The classification of rocks is based on how they form (i.e. on their **origin**) ... thus, an understanding of the **rock cycle** is very important.

- Hutton, an Englishman, came up with the idea of the **rock cycle** in the 1700's.

- Interactions among the atmosphere, hydrosphere, and lithosphere drive the **rock cycle**.

❖ consult a diagram of the rock cycle
☺ make its pattern "talk to you"

Igneous rocks

Question: What does "igneous" mean?
Answer: It means "fire", in Latin (think of the word "ignite" ... to start to burn, to catch fire).

Igneous rocks were the first rocks formed on the planet Earth, as the Earth cooled down from a molten mass of *magna*.

- In magna, the silicate tetrahedrons float freely ... and seek stability ... which they achieve via combining with other things (elements, or each other) ... thus making chains, sheets, etc.

Igneous rocks are the only type of rock found on the moon.

→ **??** within this context, what does this indicate about how and when the moon originated

→ <u>your answer</u>:

Types of igneous rocks

- two "***types***" are distinguished ... based on **WHERE** the rock forms (= crystalizes, solidifies, or consolidates)

... "where" will determine the rock's cooling history (fast / slow) and fast vs. slow cooling will determine the appearance of the rock's **crystals**

1. **<u>extrusive</u>** (sometimes called volcanic) .... **form <u>above</u> the crust**
   → **crystals are small** (= fine)
   ... because cooling was fast .... little time for crystals to grow

2. **<u>intrusive</u>** (sometimes called plutonic) .... **form <u>below</u> the crust**
   → **crystals are large** (= coarse)
   ... because cooling was slow ...... lots of time for crystals to grow

✳ The two different types of igneous rocks are determined by their cooling history.
OR ... "***Cooling history determines texture***" of igneous rocks.

Families of igneous rocks

- The "***families***" are distinguished ... based on **PATTERNS** of texture **and** mineral composition.

→ **texture**

	Family	Family	Family
1. fine grain (aphanitic) (= extrusive origin)	**rhyolite**	**andesite**	**basalt**
2. coarse grain (phaneritic) (= intrusive origin	**granite**	**diorite**	**gabbro**

→ **mineral composition**

❖ consult a diagram or figure ... of mineral composition, by family of igneous rock
☺ make its pattern "talk to you"

- **discriminator minerals**
  - **Quartz** is a ***discriminator*** for the families of igneous rocks.
    - as can be seen from the diagrams or figures (can you "see" this fact?)
    - a standard abbreviation for quartz is QTZ
    - the colour of quartz reflects the identity of other minerals it contains
  - **Orthoclase** (OR) is also a ***discriminator***.

- **mineral composition** and **colour**
  - **felsic** = composed mostly of quartz, potassium feldspar, and plagioclase
    = light-coloured
  - **mafic** = composed mostly of dark-coloured minerals containing iron and magnesium
    = dark-coloured

- The mineral composition of an igneous rock "tells us" information about the composition ... of the mantle in the area where it formed.

  - igneous rocks form from magma that has cooled
    → see "Bowen's Reaction Series"
    ... for heating magma up (melting it) and cooling it down (crystallizing it)

  - recall: magma is upper mantle that has melted (i.e. magna is a silicate melt)

Textures of igneous rocks

- **granitoid:** crystals pretty much the same size = equidimensional ... and then further classified as fine (≈1 mm) or coarse (≈ 3 cm)

- **porphyritic:** crystals are a mixture of two distinct sizes ...and the smaller, more numerous crystals form the **matrix** (= ***groundmass***)

  ... and, with reference to the crystal sizes in the **matrix**:
  - **phaneritic:** crystals visible to naked eye (= phenocrysts) ... generally 1-10 mm
  - **pegmatitic:** very large crystals ... generally larger than 1 cm
  - **aphanitic:** crystals too small to be seen by naked eye (cryptocrysts) ... generally less than 1 mm

  → **porphyritic-phaneritic** = the two types of crystals can both be seen with the naked eye

  → **porphyritic-aphanitic** = crystals visible to the naked eye embedded in a matrix where the crystals are not visible (= cryptocrysts) to the naked eye

- **aphanitic:** crystals too small to be seen by naked eye (cryptocrysts) ... generally less than 1 mm ... can be seen with a hand lens

- **glassy** or **hyaline:** crystals are much too tiny to be seen with the naked eye or a hand lens

  → these rocks appear similar to ordinary glass

- **vesicular:** formed with gas bubbles trapped ... so the rock appears to be frothy or to have air pockets

- **pyroclastic***

  ✳ are not made up of just crystals ... and thus, are *the exception to the statement that igneous rocks are made of crystals**

  - pyroclastic igneous rocks originate as sedimentary **ejecta** from volcanos ... they are extrusive ... pyro: “fire” [think: volcano]; clastic: “fragments”

    → ***ejecta*** = “things” thrown into the air (i.e., not lava) from volcanos ... classified by size (texture)

ejecta	size		pyroclastic rock
• ash	dust-4 mm	→ transported, deposited as sediment	= **tuff**
• cinder	> 4-64 mm	→ transported, deposited as sediment	= **breccia**
• bomb	> 64 cm	→ transported, deposited as sediment	= **agglomerate**

Metamorphic rocks

Question: What does "metamorphic" mean?

Answer: ... "meta" means change, "morphic" means shape or form ... thus, a metamorphic rock has undergone a change with respect to the shape or form of its mineral crystals

Question: What causes this change?

Answer: the agents of heat and pressure ... plus mineralizing fluids (hydrothermal fluids) ... leading to partial melting, or complete melting ... and then, re-crystallization

✳ the different types of metamorphic rocks are determined by the re-crystallization that results after a rock has been exposed to extremely high temperature (heat) and pressure

OR ... "***pressure-temperature conditions determine texture***" of metamorphic rocks

→ note the difference between this statement for metamorphic rocks, and the one for igneous rocks which is "cooling history determines texture"

- the ***precise definition of a metamorphic rock*** is rather complex ... it is a rock that:
  1) has a changed form ... caused by
  2) internal processes ... of heat, pressure, and hot mineralizing fluids
     3) below the zone of weathering
     4) but above the zone of melting of the Earth*
     (* note the difference here for metamorphic vs. igneous rocks)
  5) which change the texture, or rework the original minerals
  6) of the parent rock

- metamorphic processes bring about transformation from a dull-looking rock to a crystalline, bright-looking rock

→ note that this is the opposite to sedimentary processes ... which take things apart

→ example transformation from dull to bright

start with: **peat** .... which is about 60% C, 30% O_2 (+ H_2) [lowest BTU]

bituminous coal ...... which is about 80% C, 10% O_2 (+ H_2)

anthracite coal .... which is about 95% C, 2% O_2 (+ H_2) [highest BTU]

Note: Cape Breton's coal is bituminous.
BTU = British thermal unit ... heat released upon oxidizing (burning) the C to CO_2

Textures of metamorphic rocks

... some key words or terms to describe the changed texture

- foliated = being in "plates" or layers ... ⊎ like pages in a book
- to cleave = to split apart

☺ notice how **the terms for texture** below depend upon **comparison of pattern**

Appearance ... when hit the rock with a hammer:

→ **for foliated metamorphic rocks**

- slaty .... most perfect cleavage ..... have parallelism of platy (plate-like, or flat) minerals, cannot see the very fine crystals with the naked eye ... it requires very little force to make it cleave, and the cleavage surfaces are clean and smooth

  ❖ find one ... and make it talk to you
  → metamorphism = low-grade

- phyllitic .... parallel wavy cleavage ... have wavy parallelism of platy (plate-like, or flat) minerals, cannot see the fine crystals with the naked eye ... it requires very little force to make it cleave, and the cleavage surfaces are shiny and smooth

  ❖ find one ... and make it talk to you
  → metamorphism = low-grade

- schistosity ..... less perfect cleavage .... have coarse–grained crystals superimposed on the platy minerals, and can see these crystals with the naked eye ... it requires some force to make it cleave, and the cleavage surfaces are rough

  ❖ find one ... and make it talk to you
  → metamorphism = intermediate to high-grade

- gneissosity .... least perfect cleavage ..... have distinct and different colour banding of the different minerals, and can see the coarse-grained crystals with the naked eye ... it requires lots of force to make it cleave, and the cleavage surfaces are very rough

  ❖ find one ... and make it talk to you
  → metamorphism = intermediate to high-grade

→ **for non-foliated metamorphic rocks**

- are simply re-crystalized rocks ... crystals generally all about the same size ... and in many cases:
  - are made up of only one mineral, i.e. are monomineralic (e.g. marble)
  - are made up of stubby, interlocking crystals

  → must be very careful not to confuse re-crystalized rocks with intrusive igneous rocks because re-crystalized ones fit the definition of "granitoid"

❖ find one ... and make it talk to you!

Question: What non-foliated, monomineralic rocks are found in Cape Breton?
Answer:

<u>List of non-foliated, monomineralic rocks in Cape Breton</u>

1) marble .... is re-crystalized limestone or dolomite .... <u>colour</u>: is white if no mineral impurities are present; is non-white if it inherited minerals from the limestone

2) quartzite .... is re-crystalized quartz .... <u>colour</u>: is pure white if no mineral impurities are present; is greyish if there are mineral impurities present

3) anthracite .... is transformed peat, i.e. coal

Question: Where are metamorphic rocks found, in Nature, in general?
Answer:

- around mountain ranges
- near intrusives
  - recall: "intrusives" .... are hot areas of high pressure and with hydrothermal activities
  - e.g. pluton
- on cratons
  - a "craton" = the stable part of an evolving continental plate (in plate tectonic theory)
  - shields are cratons
    - e.g., the Canadian Shield ... a "continental backbone"
    - often find gold, nickle, zinc, and copper in these shields **<u>ic:</u>**

Sedimentary rocks

Question: What does "sedimentary" mean?

Answer: It refers to "deposition" ... of loose <u>fragments</u> of inorganic or organic material that have generally been *moved* (transported) from their original location to a new location where they are *deposited* and then *come together* ... to form sedimentary rock

The process of "coming together" ... *to turn into rock* ... is called consolidation, and also lithification (Latin) or petrification (Greek).

- consolidation can happen:
  - → via <u>crystallization</u> or via <u>conglomeration</u>

Example: the <u>mineral</u> **clay** .... consolidates into .... the <u>rock</u> called **shale**

↕

via .... pouring H_2O into it, and then evaporating it

<u>definition</u> of a sedimentary rock

= minerals + fragments (of rocks and/or organics) + texture

<u>Classification ... into categories ... of sedimentary rocks</u>

1) **clastic sedimentary**

- "clastic" = fragment
- these rocks contain:
  - weathered rock fragments ... that have been transported, deposited, and lithified
  - minerals: quartz, calcite, clay, etc. (specialized minerals)
- these rocks make up about 85% of all sedimentary rocks
- e.g. sandstone, siltstone, shale

2) **organic sedimentary**

- "organic" ... related to living organisms
- these rocks consist of the lithified remains of plants or animals
- e.g. coal

3) **chemical sedimentary**

- "chemical" ... related to minerals
- these rocks form by direct precipitation of minerals from solution
- e.g.
  - calcite .... rock = limestone
  - gypsum .... rock = gypsum
  - halite .... rock = rock salt
  - chert .... rock = cryptocrystaline form of quartz

4) **bioclastic sedimentary**

- "bio" ... related to living organisms / "clastic" ... fragments
- these rocks consist of broken shell fragments and similar remains of organisms
- e.g. <u>most</u> limestone

Sedimentary rocks ... another way to look at their classification

→ as "detrital" vs "chemical"
→ calcium carbonate, $CaCO_3$ = "calcite"

Origin	Texture	Sediment	Sedimentary Rock
detrital	clastic*	• gravel (> 2mm) or larger	
		- rounded grains	conglomerate
		- angular grains	breccia
		• sand (1/16 - 2 mm)	sandstone
		• silt (1/256 - 1/16 mm)	
		- does not split easily	siltstone
		- splits easily	shale
		• clay (< 1/256 mm)	
		- does not split easily	claystone
		- splits easily	shale
		• pyroclastics ...... add	from previous info
chemical	inorganic crystallization solution	• calcite, $CaCO_3$	limestone
		• dolomite, $CaMg(CO_3)_2$	dolomite / dolostone
		• varieties of quartz, SiO_2	chert
		• halite, NaCl	rock salt
		• gypsum, $CaSO_4 \cdot H_2O$	rock gypsum
		• etc.	
	organic (biochemical)	• calcite, $CaCO_3$	limestone
		• plant remains	peat & coal
		• animal remains	coquina & chalk

* for the clastic sedimentary rocks, great importance is placed on texture (which is logical in terms of the dynamic cycle of erosion), rather than on composition ... i.e., it is important to look at the sizes of the fragments

size of fragment (mm)	name of fragment (Wentworth Scale)
• 256	• boulder
• 64	• cobble
• 4	• pebble
• 2	• granule / gravel
• ½	• sand
• 1/256	• silt
• dust	• clay

Clastic sedimentary rocks

Question: What is the key to understanding **clastic sedimentary rocks** ... in terms of how these rocks are made, and what their significance is?

Answer: the **dynamic cycle of erosion** ... which could be referred to as "an equation or algorithm for sedimentary rocks"

- erosion = to bite, gnaw, or nibble away

■ ***Dynamic cycle of erosion***

weathering ——produces——→ ***fragments*** ——transported——→ ***deposited***

⥣ of: rocks at Earth's surface ... where its crust meets:
- atmosphere (air world)
- hydrosphere (water world)
- lithosphere (rock world)

⥣ via: wind (forms dunes)
H_2O
gravity

⥣ via: three processes ... that can act together
- chemical (e.g. iron streaking)
- physical ... especially temperature changes (e.g. ice ... expands and cracks rocks)
- biological ... especially the activity of bacteria

Points to note about the dynamic cycle of erosion

- fragments can only be deposited ...
  - → when there is an abrupt change ...
    - → in the energy ... associated with transportation

- the deposits .... are called "sediments" .... which are defined as "loose particles"

- where the sediments (LOOSE) rest ...
  - → lithification occurs, ... and
    - → sedimentary rock (HARD) forms

- these processes ... of weathering, transportation, deposition, and lithification ....
  - → can occur all over again ... hence a **dynamic cycle** of erosion

<u>Other points to understand ... about the minerals in sedimentary rocks</u>

• the rock-forming minerals ... for sedimentary rocks are mainly:
- quartz
- calcite ...... calcium carbonate, $CaCO_3$
- clay .... which is a "mineral family" and not found in igneous or metamorphic rock

• acid ...... will react with any carbonate (e.g. calcite) .... and "fizz"
→ thus, acid can be used as a discriminator for sedimentary rock
- because calcite is always present (is universal) in sedimentary rocks

☺ **<u>Sedimentary petrology ... the geology of the oil and gas industry</u>**

An understanding of the general characteristics of sedimentary rocks .... i.e., the fundamentals from geology .... are essential requirements in the **oil and gas industry** ... the specific area in geology is called **sedimentary petrology**.

<u>Clastic sedimentary rocks ... their general characteristics</u>

Clastic sedimentary rocks:

• are usually stratified (in layers, or "strata" .... singular, stratum)

• are generally soft

• have surfaces exposed to the atmosphere ... thus, we can talk about:
- surface and structure markings ... when there are layers
- surface markings ... when there are ripples

■ **surface and structure markings ... when there are layers:**
- parallel bedding
❖

- cross bedding (implies erosion)
❖

☞ With respect to "layers" of sedimentary rocks ... an important recognition, made in the 1600's was that .... "that which is laid down first, is the oldest" (assuming no upheavals).

- this important understanding is called the <u>Law of Superposition</u>
- today, this understanding is a basic tool of the oil exploration geologist

▪ **surface markings ... when the focus is on surface only:**

- mud cracking
    ... pattern of the curl of the chunks ... tells you top and bottom, and thus youngest and oldest
    ❖

- ripple marks
    ... pattern tells you about the movement of water in a shallow area
        → a wave can only erode to a depth of ½ its wave length
        ... ripple marks are not found, therefore, in deep water

• two fundamentally different types of ripple marks

1) current .... e.g. a stream .... movement is only one way
    ❖ ... waves look a "little drunk" ...... cannot tell top from bottom

2) oscillation .... e.g. a shoreline .... movement is back and forth
    ❖ ... waves are symmetrical .... can tell top from bottom

QUESTION: How do continents form?

Plate Tectonics theory

❒ Read: *The Last Billion Years; a Geological History of the Maritime Provinces of Canada*

Non-renewable natural resources

❒ Read: *The Last Billion Years; a Geological History of the Maritime Provinces of Canada*

Oil and gas

Metals and minerals

BIOLOGY

☺ ... its Big Questions about Nature

1) What is life?

2) What are the major categories of life on Earth? ... Biodiversity

3) How did life originate? ... Chemical Evolution Theory

4) How did life diversify? ... Theory of Evolution

5) Do “basic building blocks” of life exist? What are they? ... Cell Theory

6) Where in the cell is the information for life stored, and how is it accessed and used? ... DNA and Gene Theory

7) How do living organisms convert energy?

❒ Read: *Integrated Science*

QUESTION: What is life?

Answer:

- dictionary definition: the property that distinguishes the living from the dead
  - problem ... contains the idea of a property, something similar to what scientists at the end of the last century believed in and called a vital force

- old idea: vitalism / vital force ... unexplainable, magical, and invisible force inhabiting all living organisms, and unique to life

  ... a live organism was inhabited by this special force, whereas, in a dead organism the vital force had departed

  ... not an idea acceptable to modern biology, as it is not testable by experimentation (scientific method)

- modern science approach: consider the characteristics of "things" considered to have life, rather than life itself

  - "things" = living organisms

☺ A living organism ...

1) is an ordered system ... open to matter and **energy** flow.

   Living organisms are energy beings.

2) is a chemical factory ... that captures energy and matter from its environment ... and transforms them into structures and processes that make life possible.

   Living organisms are stardust.

3) consists mainly of water ... and thus, is a water-based environment.

   Living organisms are waterbags.

Living organisms: a list of their characteristics

The modern scientific approach is to consider the *characteristics of things that have life*, rather than trying to answer the question "what is life?" directly.

Therefore, the list of the *characteristics of things that have life* that is generally used in biology today is as given below. Living organisms:

1) have complex organization (organization implies "ordered")

2) utilize energy

3) exhibit growth & development

4) respond to their environment (stimuli)

5) capable of reproduction

6) maintain homeostasis (regulate their internal environment ... an ordered environment)

7) show adaptation to environment (evolutionary ... variation based on heredity)

Notes:

- The list must be used as a whole ... as there are major problems associated with using any one characteristic by itself.

- The involvement of **energy** is of fundamental importance ... **living organisms are energy converters**!

QUESTION: What are the major categories of life on Earth?

The **<u>different kinds, or types</u>**, of living organisms found on Earth are referred to as **species**.

■ **Species are "named".**

- Every species known to modern biology has been given a "scientific name" that consists of two words. This system of naming is called the *binomial system of nomenclature,* and was suggested by Carolus Linnaeus (a Swedish botanist) in 1700's.
  → The scientific name for humans, for example, is *Homo sapiens*.

- The scientific name, because it has two words, is called a <u>binomial</u>. The first word is referred to as the *generic word*, and the second as the *specific epithet*.
  → The generic word in the scientific name for humans is *Homo*.
  → The specific word in the scientific name for humans is *sapiens*.

- Biology has rules as to how scientific names <u>must</u> be written.

  - use the Roman alphabet

  - capitalize the first letter of the generic word (but not the second word)

  - do not attempt to provide a plural or a singular ... these concepts do not apply

  - italicize or underline the two words (do not underline the space between them)

    e.g. *Homo sapiens* OR <u>Homo</u> <u>sapiens</u>

  - abbreviate, if desired, by giving the capitalized first letter of the generic word followed immediately by a period, and then the specific epithet in full; italicize or underline

    e.g. *H. sapiens* OR <u>H</u>. <u>sapiens</u>

- Each species has one, and only one, scientific name.

- Many species, particularly those with which we humans have great familiarity, have been given "common names" (= vernacular names). A species can have several common names, and they are generally different in the different languages.

■ **Species are "classified".**

- Every species known to modern biology is "classified" using the *hierarchical system of classification* suggested by Carolus Linnaeus (a Swedish botanist) in 1700's.

  → This system consists of species (as the lowest level) within a *nested set* of increasingly higher level categories.

  → The standard levels in the hierarchy are:

  Kingdom
  Phylum
  Class
  Order
  Family
  Genus
  Species

- Modern biology generally works with a *five kingdom system of classification*. This number is currently in the process of being changed, however. New information being obtained about living organisms is causing biologists to change their ideas about the relationships among organisms, and thus also change the way they are classified.

Five kingdoms of living organisms

Monera

Protista

Fungi

Plantae

Animalia

QUESTION: How did life on Earth originate?

This is a **BIG QUESTION** ...that has puzzled humans for millennia.

Suggested answers:

1) supernatural outside agency
   ... divine source (i.e. not natural)

2) outerspace
   ... natural source, but from elsewhere in the universe

3) unknowable
   ... life today too different from original to ever understand

4) chemical evolution ← **the theory held by (most of) modern science**
   ... in a series of gradual steps over extremely long period of time:
   - from inanimate (non-living) matter → macromolecules → primitive cells (life)

Chemical evolution theory of origin of life on Earth

recall:

- formation of elements H and He at time of Big Bang (18 bya), additional elements up to Fe in fusing stars and up to Ur in supernovae ... and these elements being "spit out" into space
- formation of planet earth (4.5 bya) ... from remnants of original H and He dust, together with other elements from supernovae
- primitive earth condenses ... with formation of the **1st atmosphere**
  - fate of 1st atmosphere: "escapes" because earth's gravitational field at that time too weak to hold it
- as time passes ... earth continues to undergo gravitational compression ... this, together with radioactive decay generates enormous heat at centre results in centre of planet melting (becomes molten, liquid rock) ... intense heat drives out various gases by way of volcanic action ... with formation of the **2nd atmosphere**
  - fate of 2nd atmosphere: retained ... but becomes modified much later
  - surface of planet:
    - receives torrential rainfall which erode rocky surfaces
    - oceans form as rainwater collects into vast areas ("oceans")
      ... eroded material causes oceans to be salty and mineralized
- early oceans thought to have been thermodynamically stable
  → no tendency for contents or substances to react with each other to form more complex molecules

Question: How could macromolecules arise in a thermodynamically stable environment?
Answer: ...

→ as an **hypothesis** **… abiotic synthesis of small organic molecules** as a result of energy input ... suggested in 1920's by Oparin and Haldane ... in which the possible sources energy input to system are:
- photons ... µv light ... from sunlight (considered MOST IMPORTANT)
- heat ... from earth's centre (volcanoes) and sunlight
- radioactive decay ... of unstable isotopes of elements
- lightning

→ **experimental test** of hypothesis: in laboratory in 1953 by Miller and Urey
- their experimental set-up
- their methodology
- their results ... formation of a variety of organic compounds including amino acids, sugar residues, N-containing bases

→ **implications** of results:
- under the conditions of heat, humidity, energy, and raw materials similar to those probably present on the early earth (atmospheric gases and salty oceans) ... building blocks of major biological macromolecules could have been formed

Question: OK, the monomers are in place ... what next ... to get to the true cells (1st life)?
Answer: ... suggested steps:

1) monomers → polymers ... polypeptides & polynucleotides
... clay surfaces acting as:
- catalysts ... ions in clay
- concentrating areas ... with evaporation
- warming areas ... with soaking up of sunlight

2) polymers → microdrops (as: procells or aggregates)
- examples of types of microdrops that can be formed in the laboratory:
  - co-acervate droplets (from actual macromolecules in today's cells)
  - proteinoid microspheres (from dry amino acids shaken in water)
  - liposomes (from phospholipids shaken in water)
- important properties of microdrops:
  - form spontaneously
  - are structurally organized and separate from external environment
  - absorb molecules from external environment
    → increase [substrate inside] ... Rx more likely to occur inside

3) microdrops → true cells (i.e. 1st life forms)

IMPORTANT UNDERSTANDING: true cell = ***container*** + ***information & function system***

- *container:* microdrop of phospholipids
- early oceans with extremely high numbers of ... perhaps billions/tsp
- most microdrops very unstable ... last only milliseconds
- some microdrops last much longer
  → long enough for chemical Rx to occur inside ... with products that might:
  a) stabilize them
  b) serve as catalysts for other chemical Rx
  c) cause droplets to grow
  - growth accompanied by fragmentation ... new microdrops with identical contents and properties to "parent" microdrop = primitive reproduction

- *information & function system* (central dogma of modern biology): DNA → RNA → protein
- suggestion is that RNA played a very important role in early self-replicating systems
- RNA becomes associated with DNA ... evolutionary advantages:
  - DNA is more chemically stable (because is double-stranded)
  - DNA offers more of a correction method (proof reading) for accurate duplication

ANOTHER IMPORTANT UNDERSTANDING
- ***key relationship of Central Dogma:*** DNA → RNA → PN
- **3 monomers of DNA → 3 monomers of RNA → 1 monomer of PN**

Gaps in our understanding (chemical evolution theory)

- how a certain 3 nucleotide sequence became the "code" for a specific amino acid ... but there is basically only ONE genetic code for ALL of the enormous diversity of living organisms
- did the information & function system evolve inside or outside of a container ... arguments on both sides, with the one for "inside" having the edge

Other important points

1) heterotrophs were the earliest organisms on planet earth

- they used as food sources, the organic molecules found free in the soupy environment in which they lived

  note: they were dependent on previous, abiotic synthesis of this molecule
  important: do you understand the difference between biotic and abiotic synthesis?

2) appearance of the **autotrophs** ... after the heterotrophs: As the food supplied dwindled excessively approaching the point of nothingness, there would have been strong selection for organisms with the abilities to synthesize their own food sources ... i.e., for biotic (vs. abiotic) synthesis of small organic molecules. Organisms that can synthesize their own food are called **autotrophs**.

✷ Synthesis requires an energy source.

- *abiotic:* those four sources previously listed (but especially μv radiation)
- *biotic:*
  a) *chemosynthetic autotrophs* = from energy from chemical bonds (e.g. in H_2)
  b) *photosynthetic autotrophs* = from energy in sunlight

- Only after photosynthetic organisms evolved did gaseous oxygen (O_2) accumulate in the earth's atmosphere.
  → O_2 is a waste product of glucose synthesis by plants

- O_2 in the atmosphere is converted by sunlight to O_3 (=ozone)
  → ozone blocks most μv from reaching surface of planet
  → living organisms have (by adding O_2 to the atmosphere) modified their environment in such a way that if life on earth were wiped out ... it would likely be impossible for it (life) to re-evolve along lines similar to those hypothesized to have led to the origin of life in the first place

QUESTION: How did life on Earth diversify?

Answer:
- change through time = evolution
- change in populations of living organisms over time = Darwin's Theory of Evolution by Natural Selection (Evolutionary Theory)

Evolutionary theory

UNIFYING CONCEPT OF MODERN BIOLOGY
Nothing in biology makes sense, except in the light of **evolution**
(Theodosius Dobzhansky)

FACT: evolution (change over time) has occurred
- it is considered a **fact** that **evolution has occurred or happened** among living organisms on Earth ... this was well documented and broadly accepted before Darwin

- evolution defined: change through time (general usage); descent with modification (Darwin); change in a lineage of populations between generations (Ridley 1993); change via the sorting of genetic-based variation within a particular environmental context (Thompson 1998)

HYPOTHESIS: Darwin's contribution (1859) ... evolution occurs by way of **natural selection** ... i.e., an explanation of <u>how</u> evolution occurs, the mechanism of evolutionary change

THEORY: Darwin's hypothesis is now accepted as a **theory** in modern biology. Indeed, it is accepted by the vast majority of biologists and is considered to be the **UNIFYING CONCEPT of modern biology**.

THEORY OF EVOLUTION BY NATURAL SELECTION

• an outline of the development of the theory (from Mayr)
• note: Darwin had no knowledge of genetics or the "central dogma"

Fact #1: all species have great potential fertility such that one might expect an exponential increase in populations of organisms over time
Fact #2: populations normally display stability, i.e. potential for exponential increase not realized
Fact #3: natural resources ("food") are limited and in a stable environment they remain relatively constant
Inference #1: struggle for existence among individuals (Malthus) **[only some survive]**
Fact #4a: no two individuals are exactly the same
Fact #4b: every population displays enormous variability
Fact #5: much of the variation found among individuals is heritable
Inference #2: there is differential survival among members of a population, i.e. natural selection **[survival is not random ... survivors are "selected" by natural environment]**
Fact #6: the earth is ancient, and thus both the struggle and natural selection have been going on for a long time
Inference #3: through many generations ... evolution by way of natural selection (Darwin) ... CONCLUSION **[survivors reproduce ... change in genetic lineage through time ... i.e. evolution]**

diagram

***Proteins* = the key relationship between "unifying concept" & "central dogma" of modern biology**
• biological significance in an organism ... working molecules ... **survival** (day to day) of organism

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• genetic information for their synthesis ... DNA ... **survival** (generation to generation) of species

QUESTION: Do basic building blocks of life exist? What are they?

Answer: Yes, basic building blocks of life exist ... they are called "cells".

Cell Theory ... of Modern Biology ... three major points:

1) cells are the basic units of life, both functionally and morphologically
2) all living organisms are made up of cells
3) all cells come from pre-existing cells

Perspectives on the cell

1) *structural perspective:* cell = closed container + contents

- closed container ... plasma membrane
- contents ... fluid (water) containing dissolved ions and molecules and tiny structures called organelles

→ two fundamental types: prokaryotic cells and eukaryotic cells

2) *operational perspective:* cell = information system + function system

- information system ... DNA
- function system ... proteins

3) *dynamical perspective:* cell = site of energy flow and conversion

- in the cytoplasm ... site of glycolysis (& substrate level phosphorylation)
- in the mitochondrion ... site of oxidation of pyruvate, citric acid cycle, chemiosmotic phosphorylation (& substrate level phosphorylation)
- in the chloroplast ... site of glucose synthesis

Prokaryotic vs. eukaryotic cells

A cell is either prokaryotic or eukaryotic ... it cannot be both.

The first living organisms on Earth were prokaryotic cells ... and, thus, prokaryote cells are the ancestors of eukaryotic cells (and thus, also of all life forms).

- prokaryotic: Kingdom Monera
- eukaryotic: Kingdoms Protista, Fungi, Plantae, and Animalia

The difference between prokaryotic and eukaryotic cells is based mainly on structure.

1) *prokaryotic cells*

- container: plasma membrane
- contents:
  - DNA located in nuclear region (but not "membrane-bound" and thus, no true nucleus)
    ... chromosome: singular, circular in shape, and not associated with a protein
  - organelle: ribosomes only

2) eukaryotic cells

- container: plasma membrane
- contents:
  - DNA located in true nucleus (an area that is "membrane-bound")
    ... chromosomes: several, linear in shape, and associated with a histone protein
  - organelles: ribosomes and numerous others

List of organelles found in eukaryotic cells … and their major functions

Organelle	Function
• nucleus	storage of genetic information (DNA)
• ribosome	synthesis of protein
• endoplasmic reticulum (ER)	transportation system within cell
smooth (SER)	synthesis of some molecules, detoxification
rough (RER)	synthesis of some molecules
• Golgi complex	collection, modification, packaging, distribution
• lysosome / phagolysosome	degradation of molecules
• cytoskeleton	support and movement of cell
• flagellum (flagella) / cilium (cilia)	movement of cell
• centriole	cell division
• mitochondrion	energy conversion within cell
• chloroplast (in photosynthetic cells only, e.g. plants)	energy conversion within cell

Types of macromolecules (polymers, or big molecules) found in cells

There are four major classes of macromolecules ... associated with cells and living organisms:

1) nucleic acids
2) proteins
3) carbohydrates
4) lipids

These "big" or "macro" molecules (polymers) are made by linking "small" molecules or building blocks (monomers) together. The monomers for each of the classes are:

1) nucleic acids .... nucleotides
2) proteins .... amino acids
3) carbohydrates .... monosaccharides
4) lipids .... fatty acids, glycerol, triglycerides

The macromolecules have, in general, the following functions in cells:

1) nucleic acids .... genetic information storage and transfer
2) proteins .... "working molecules" with 1000's of different, specific jobs
3) carbohydrates .... energy and structure
4) lipids .... energy and structure

The macromolecules are made (synthesized) by cells in different sites:

1) nucleic acids .... in the nucleus
2) proteins .... in ribosomes
3) carbohydrates .... glucose in chloroplasts; disaccharides and polysaccharides in SER
4) lipids .... in SER

QUESTION: Where in the cell is the information for life stored?

Answer: The "information for making life" ... i.e. a living organism ... is stored in molecular form ... in a molecule called DNA (deoxyribonucleic acid) ... which itself is stored in the nucleus of an eukaryotic cell and in the nuclear region of a prokaryotic cell.

Nucleus ... eukaryotic cells

- site of genetic information storage (DNA)
- site of nucleic acid synthesis (DNA and RNA)
- chromosomes ... DNA molecules (wound around histone proteins)
- nuclear envelope (a doubled membrane, with pores that are plugged with proteins)

■ *nucleic acids and DNA ... eukaryotic cells*

There are only two types of nucleic acids ... and each has a fundamental biological role:

- DNA (deoxyribonucleic acid): genetic information storage molecule
- RNA (ribonucleic acid): genetic information transfer molecule

Nnucleic acids are molecules made by linking monomers (building blocks), called nucleotides, together ... when linked together, the resulting nucleic acid can also be called a polymer or a *polynucleotide chain.*

Each nucleotide has three parts:

1) a phosphate group: — OPO_3^{2-} ... which gives "acid" properties to nucleic acid
2) a 5 carbon sugar
   - → in DNA: deoxyribose
   - → in RNA: ribose
3) a nitrogen-containing base
   - → possibilities for the identity of the nitrogen-containing base in a nucleotide
     - in a nucleotide of DNA ... A, G, C, T (but only one per nucleotide)
     - in a nucleotide of RNA ... A, G, C, U (but only one per nucleotide)

... the nitrogen-containing bases fall into one of two categories

- *purines* (2 C-N rings in the molecule ... i.e. large molecule):
  - adenine A
  - guanine G
- *pyrimidines* (1 C-N ring in the molecule ... i.e. small molecule):
  - cytosine C
  - thymine T
  - uracil U

✷ ***key understanding:*** **it is the N-containing base ... that labels the whole nucleotide**

■ *DNA (__d__eoxyribo__n__ucleic __a__cid)*
• SHAPE = double helix
- "double" ... because there are two polynucleotide strands
  - → linear sequence of nucleotides on a strand = primary structure (1°)
- "helix" because strands wound around each other
  - → strands held together via H bonds ...between adjacent N-containing bases

■ *RNA (__r__ibo__n__ucleic __a__cid)*
• different types:
- tRNA ... transfer RNA
  - → carries or "transfers" amino acids to ribosome
- rRNA ... ribosomal RNA
  - → a major structural component of a ribosome (along with protein)
- mRNA ... messenger RNA
  - → is the genetic information "message" as to how to make a protein •

KEY RELATIONSHIP ... ***CENTRAL DOGMA:*** DNA → RNA → PN

3 monomers of DNA (→ 3 monomers of RNA) → 1 monomer of PN

you must keep in mind that a:
- monomer of DNA = nucleotide
- monomer of RNA = nucleotide
- monomer of PN = amino acid

key understandings:

**1) the linear sequence of monomers on the DNA molecule <u>dictates</u> ...
... the linear sequence of monomers for the PN**

**2) the linear sequence (1° structure) of the PN <u>dictates</u> ...
... the folding pattern (shape) of the PN molecule**

3) the shape of the PN molecule <u>determines</u> its function

QUESTION: How is DNA accessed and used?

Gene theory ... the central dogma of modern biology

☞ under construction

Transcription and translation

☞ under construction

Proteins ... the working molecules in the living organism

- fundamental biological role: the "working" molecules or the "functioning molecules" in the intracellular and extracellular environments
- are THE result of the genetic information being "expressed" or, put another way ... the central dogma: DNA → RNA → protein
- are the most abundant macromolecule in living organisms ... may constitute up to 50% of the dry weight of a cell
- occur in: a) all cells, and in all parts of a cell ... including membranes
  b) extracellular fluids
- have 1000's and 1000's of different work / functions / jobs / roles ... which can be categorized into about eight major groupings

major categories of work / functions ... performed by proteins

1) enzymes ... in metabolism
- all chemical reactions in living organisms are catalyzed by enzymes

2) structure
- e.g. keratin (hair, nails); collagen (cartilage); fibrin (blood clots)

3) regulatory
- as chemical messengers ... protein hormones (e.g. insulin, growth hormone)
- as repressors of genetic information

4) defense
- e.g. antibodies of immune system

5) transport
- through the body (e.g. haemoglobin ... carrier of O_2 to cells)
- across plasma membranes (e.g. as channels and pumps)

6) contractility / mobility
- e.g. in muscles (actin and myosin); in microtubules of cytoskeleton (tubulin); in flagellar "tail" of sperm (tubulin)

7) cell labeling / recognition
- e.g. CD4 on T4 lymphocytes; MHC-I on all nucleated cells; MHC-II on macrophages

8) nutrient storage
- not a common means of energy storage in the human body
  - proteins are generally only metabolized (broken down) for energy when the body is in a starvation state
  - some rare examples of where proteins do have a normal energy or nutrient storage role ... milk (casein), eggs (albumin)

■ **AMINO ACIDS** ... are the monomers of proteins

- molecular structure of a "no-name" (or generic) amino acid
  - four parts:
    1. the central C
    2. a carboxyl group
    3. an amino group
    4. an R group (or R side chain)

- amino acids are linked together, by peptide bonds, to form a polypeptide chain ... i.e. the protein molecule
  - parts of the chain: a) backbone ... AND dangling from it
    b) an R group from each amino acid

A "chain" representing a *polypeptide chain* is sketched below ... each box in the chain represents an amino acid. You add an R group to each amino acid, to make the sketch more complete.

NH_2 -☐ - ☐ - ☐ - ☐ - ☐ - ☐ - ☐ - ☐ - ☐ - ☐ - ☐ - ☐ - ☐ - COOH

- there are 20 different amino acids, which differ from each other ONLY by the make-up of the R group ... they can be grouped into three categories, based on chemical properties of the R group:
  - hydrophilic (likes water ... is soluble)
  - hydrophobic (hates water ... is insoluble)
  - so-so (is partially soluble)

☞ **In your efforts to understand proteins as the <u>working molecules</u> in the cell ... here is the essential fact:**
• *key relationship:* ABILITY TO WORK / FUNCTION ↔ SHAPE OF MOLECULE

☞ **In your efforts to understand <u>protein shape</u> ... here are the essential facts:**

• SHAPE, or folded pattern of a protein molecule: has levels of structure ... 1°, 2°, 3°, 4°

1° ... primary structure: is the linear sequence (order) of amino acids

2° ... secondary structure: first level folding ... with two types of regularly repeated shapes (regions): α helix and β pleated sheet
→ driven by H-bonding along the backbone

3° ... tertiary structure: second level folding (folding on folding)
→ driven by hydrophobic interactions of the R groups ... resulting in a <u>hydrophobic</u> inner and a <u>hydrophilic</u> outer to the protein molecule

4° ... quaternary structure
→ folding of one polypeptide chain around another, and maybe another, and maybe another

QUESTION: How do living organisms convert energy?

Answer: Through a process called **photosynthesis**, some organisms (e.g. plants) are able to convert energy in sunlight into chemical bonds in the sugar molecule glucose (and then use the glucose as their food source). In a process called **cellular respiration**, other organisms (e.g. humans, and also plants) convert energy in glucose (the *energy food molecule*) into chemical bonds in the molecule ATP (which they then use as the *energy currency molecule* to pay "cellular energy bills").

✺ organelles of energy conversion in the eukaryotic cell

- for photosynthesis (glucose anabolism ... "making glucose")
  organelle: chloroplast
  energy conversion: .... from sunlight
  .... to chemical bonds in glucose

- for cellular respiration (glucose catabolism ... "breaking glucose")
  organelle: mitochondrion
  energy conversion: .... from chemical bonds in glucose
  .... to chemical bonds in ATP

✺ the two most important molecules in energy conversion are glucose and ATP

- molecular structure of glucose (draw it)

- molecular structure of ATP (draw it)

Photosynthesis

• overall chemical reaction: **$6H_2O + 6CO_2$** $+ 6H_2O$ → **$C_6H_{12}O_6 + 6O_2$** $+ 6H_2O$

→ capture the electromagnetic energy in sunlight ... use it to excite electrons ("high energy electrons")

... and then ... use these high energy electrons to make glucose

... i.e. convert the energy in sunlight to chemical bonds (pairs of electrons) in glucose

• steps

→ first ... produce high energy e^-'s ... via the

• **light reactions** ***... use energy from sun to excite electrons from H_2O***

... this process requires the green pigment chlorophyll

... this process also removes H^+ ... and leaves O_2 as a waste product

→ second ... produce glucose ... via the

• **dark reactions** ***... use high energy e^-'s to synthesize glucose***

• **important points in photosynthesis**

- $6H_2O + 6CO_2 \rightarrow C_6H_{12}O_6 + 6O_2$ [plus 6 more H_2O on both sides of equation]
- endergonic ... energy captured
- oxidation of water
- reduction of carbon
- biologically useful product: glucose
- waste product: O_2

• examples of photosynthetic organisms ... you provide some! (Kingdom and common name)

Cellular respiration

Our human bodies are powered by the "chemical energy" in the food we eat, especially that in the carbohydrate (sugar) molecule **glucose**.

"**Glucose catabolism**" in our bodies involves conversion of the electromagnetic energy in the chemical bonds in the glucose molecule (the *universal energy food molecule*) ... into electromagnetic energy in bonds in a molecule called ATP (the *energy currency molecule*) ... energy which is then used to pay almost all "energy debts" in the cells making up our bodies.

→ the overall process by which ATP is synthesized in cells is called **cellular respiration**
→ entry of glucose into cells ... from the bloodstream ... is regulated by the hormone insulin

• two possibilities for cellular respiration (glucose catabolism):
1) **aerobic respiration** (= complete catabolism)
• use oxygen as a "dumping ground" for the "waste" electrons
... after complete catabolism of glucose
2) **anaerobic respiration** (= incomplete catabolism)
• use a small organic molecule as a "dumping ground" for the "waste" electrons
... after incomplete catabolism of glucose (= glycolysis)

AEROBIC RESPIRATION

• overall Rx: $\mathbf{C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2}$ **+ energy liberated**
→ capture the energy liberated ... in chemical bonds in ATP
→ i.e., convert the ***energy in the high energy bonds (electrons) of glucose*** (the energy food molecule) into ***high energy bonds (electrons) in ATP*** (the energy currency molecule)

• ***part one*** (three phases) ... remove the ***high energy electrons*** from glucose (oxidation)

• glycolysis ... occurs in cytoplasm of cell
→ at the beginning: 1 X 6C molecule
→ at the end: 2 X 3C molecule
□ **removal of high energy electrons**

• oxidation of pyruvate ... occurs in matrix of mitochondrion
→ at the beginning: 2 X 3C molecule
→ at the end: 2 X 2C molecule
□ **removal of high energy electrons** (and loss of $2CO_2$ as a waste product)

• citric acid cycle (= Kreb's cycle) ... occurs in matrix of mitochondrion
→ at the beginning: 2 X 2C molecule
→ at the end: nothing
□ **removal of high energy electrons** (and loss of $4CO_2$ as a waste product)

• ***part two*** ... use the ***high energy electrons*** to make ATP
- total production of ATP (phosphorylation) = 36 ATP / glucose
  ✳ via two different routes for the synthesis of ATP in cell:
    • MINOR means: substrate level phosphorylation ... 4 of 36
    • MAJOR means: chemiosmotic phosphorylation ... 32 of 36

■ **substrate level phosphorylation** ... a very simple route
  □ "pickpocketing" of the high energy e^-'s along with a phosphate group
  ... by ADP, from a substrate with a "high energy phosphate group"
  ... to yield (produce) ATP directly

■ **chemiosmotic phosphorylation** ... a much more complex route
  □ get the high energy e^-'s
  □ move the high energy e^-'s
    • to e^- transport chains with H^+ pumps
      → moved via co-enzymes ("shuttlebuses" that pick up and dump out "passengers")
        • NAD^+ (= oxidized form) ... NADH (= reduced form)
          Rx: $NAD^+ + 2e^- + H^+ \rightarrow NADH$
        • FAD (= oxidized form) ... $FADH_2$ (= reduced form)
          Rx: $FAD + 2e^- + 2H^+ \rightarrow FADH_2$
        • $NADP^+$ (= oxidized form) ... NADPH (= reduced form)
          Rx: $NADP^+ + 2e^- + H^+ \rightarrow NADPH$
  □ use the high energy e^-'s to pump H^+ ... to set up a H^+ gradient
    • high energy e^-'s "flow" on "e^- transport chains with H^+ pumps" in membranes
      → e^- transport chain = a series of membrane proteins
      → H^+ pump = transmembrane protein
    • high energy e^-'s are the source of energy that runs H^+ pumps
      → pumping H^+ ... to build transmembrane proton (= H^+) gradient
  □ use the energy of H^+ moving down their gradient to make ATP (phosphorylation)
    • involvement of the transmembrane protein symbolized by the "lightbulb"
      → stem: the diffusion channel for H^+
      → bulb: the enzyme "ATP synthase"

• ***also:*** "dump" the low energy electrons (they have now been "stripped" of their high energy)
  • onto O_2 ... i.e., reduction of oxygen
  • in combination with H^+ ... to yield H_2O ... as the waste product
  ✳ living organisms are "water bags" ... water is <u>not</u> a problematic waste product

• ***also:*** exhale the CO_2 ... which would otherwise be a problematic waste product

- overall efficiency of energy conversion
  - 36 ATP X 7.3 kcal/mole (for each ATP) = 262.8 kcal / mole
  - 7 C-H bonds X 99 kcal/mole = 693 kcal/mole (really 686)
  - 262.8 / 686 = 38% efficiency in energy conversion from glucose to ATP
  - where is the remainder of the energy?

    ... lost as: heat and waste products (H_2O, CO_2)

- **important summary points for aerobic respiration**
  - $C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$
  - exergonic ... energy liberated
  - oxidation of glucose
  - reduction of oxygen
  - biologically useful product: energy recaptured in ATP
  - waste products: H_2O and CO_2

<u>**ANAEROBIC RESPIRATION**</u>

- begins with glucose catabolism ... but only through the glycolysis phase
- after glycolysis ... different possibilities as to the fate of the "waste electrons"

  → fate depends on the species of living organism

1) lactic acid fermentation

   ... dump the electrons onto pyruvate to give → lactic acid

   e.g. humans ... muscles

   bacteria ... commercial applications: yogurt, cheese

2) alcohol fermentation

   ... dump the electrons onto a 2C molecule to give → ethyl alcohol

   e.g. yeast ... commercial applications: beer, wine, bread

ABORIGINAL KNOWLEDGE

❒ Read: *Native Science; Natural Laws of Interdependence*

Foundations of Indigenous Education (*sensu* Gregory Cajete)

☞ under construction

Visionary

Artistic

Affective

Communal

Concepts about space and time

☞ inserts

Biodiversity

Traditional Ecological Knowledge (TEK) / Indigenous Knowledge (IK)

☞ inserts

United Nations 1992 Convention on Biological Diversity

❐ Read: information from the United Nations Environment Programme, Secretary of the Convention on Biological Diversity

- web site: http://www.biodiv/org/socio-eco/traditional/default.asp

Indigenous Knowledge and Development Network

❐ Read: information on the Indigenous Knowledge and Development Network

- web site: http://www.nuffic.nl/ik-pages/ik-network.html

Context of Traditional Ecological Knowledge

❐ Read: *Context of Traditional Ecological Knowledge* (from Berkes 1999)

Intellectual roots of Traditional Ecological Knowledge

❐ Read: *Intellectual roots of Traditional Ecological Knowledge* (from Berkes 1999)

Mi'kmaq

☞ insert

Integrating local and Traditional Ecological Knowledge into fisheries management in Canada

❐ Read: *Integrating local and Traditional Ecological Knowledge into fisheries management in Canada* (by Hipwell 1998)

☞ inserts

❒ Read: information on the Indigenous Knowledge and Development Network

- web site: http://www.nuffic.nl/ik-pages/ik-network.html

SOURCES

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ARTICLES