THE COGNITIVE TOOLS OF EARTH EXPANSION

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The philosophical framework:

A knowable material reality with necessities, but also with possibilities and potentialities, exists independent of human thought and action.

Questions to answer:

- Is the dominant character of processes inside the Earth **reversible** or **irreversible**?

- If irreversibility dominates, is it **degrading** or **upgrading**?

- If upgrading, is it a result of **one major catastrophic** event that happened very early in Earth's history, or is it an ongoing process and a result of **many episodes**?

- Is the Earth a **Heat Engine** (Gravity mechanics) or a **Stress Engine**(Quantum mechanics)?

Some cognitive tools from Physics:

- **Reversibility,** that is the return to the original values of thermodynamic variables, requires:

  a) **Thermal equilibrium**, that is slow change so that all thermodynamic variables are well defined at all times and their return to their original values is possible by reversing the external conditions.

  b) The action of **conservative forces**, that is path and time independent forces, i.e., gravity, and the **absence of non-conservative forces**, i.e., friction.

  c) **Independent particles**, i.e., ideal or very dilute gases.

  d) **No heat loss** to the environment (insulation and/or very fast change).

- **Irreversibility**, that is the conversion of some of the kinetic energy into heat, and the impossibility of return to the original values, is a result of :

  a) **Lack of thermal equilibrium**, that is fast change so that the thermodynamic variables are not well defined at all times.

  b) **Non-conservative forces**, that is path and time dependent forces, i.e., friction.

  c) **Interaction of particles**, i.e., real gases, fluids.

  d) **Lack of insulation**.

- **Thermal energy**, that is the sum of **translational**, **rotational** and **vibrational energy** is only a **very small fraction**, of the order of 10^{-4} to 10^{-5}, **of electronic energy**.

- **Entropy, S,** is a measure of the amount of the **disorder** in a **thermal system**. Like thermal energy, is a **function of state**, and only **changes in entropy** have physical significance. **Entropy changes are path independent**. For infinitesimal reversible transformations, **dS º dQ/T**.

- For ideal gases **entropy, that is disorder, decreases as temperature decreases** :

$$dS = S\,(T,V) - S(T_0 , V_0) = C_V \ln\,(T/T_0) + nR\ln\,(V/V_0).$$

- In a **thermally isolated-closed** system **reversibility**, that is the lack of changes in entropy (dS/T = 0), is possible because S(B) - S(A) ³ 0.

- In a **thermally open** system **complete reversibility is impossible**, that is dS/T< 0 and S(B) - S(A) < 0.

- Therefore in the **real world complete conversion** of thermal energy into mechanical work is **impossible**, without any further effect. In other words complete reversibility is impossible, **unless there**

is a constant input of thermal energy.

- The effect of **pressure** on the **entropy** of a crystal can be expressed by the formula $\mathbf{S = klnW}$, where **k** Boltzmann's constant (1.38×10^{-23} J/K) and **W** the probability of realization of various lattice arrangements or **degrees of freedom**. In other words **the higher the pressure**, the stronger the restriction of the mobility of atoms, the fewer the degrees of freedom and the smaller the probability of realization of various lattice arrangements, and consequently **the lower the entropy**.

- For **ideal or very dilute gases** PV/n = RT, where P, pressure, V, volume, n, number of moles, T, temperature, and R = 8.314 J/mol K.

- **Ideal fluids** are :

     a) **frictionless**,

     b) **incompressible**,

     c) their **density is constant**, in time and space, that is they are **homogeneous** and **isotropic**

     d) the exerted force is **pressure independent**. In other words the particles of an **ideal fluid** move about with **complete freedom**.

- In **real fluids** the particles move with **restricted freedom**.

- **Newton's theory of gravitation** (U = GMm/r) refers to bodies that move with speed u<<**c**, and there is nothing between them, i.e., **no field**, is a limiting case of **Einstein's general theory of relativity** (U = m.c^2) and of the **equivalence principle** that introduces the notion of the **field** and explains **gravitation** in terms of **distortion-curvature of space**.

- The **equivalence principle** states that **no experiment can distinguish** between:

     1) a **physical system at rest**, subject to a uniform gravitational force; and

     2) a physical **system uniformly accelerating** in the absence of gravity. In other words the gravitational and the inertial masses are identical when **g** and **a** have the same numerical values.

- The **special theory of relativity** is based on two postulates :

     1) **The laws of nature are the same in all frames of reference in relative motion at constant velocity,** that is there are **no objects** that are **'really stationary'** and others that are **'really moving'**.

     2) **The speed of light in empty space has the same value to all observers, regardless of their state of motion**, that is the velocity of light is the same regardless if the observer is stationary or moving. In other words, according to that postulate, no material body can reach the speed of light, because if it does it will be at rest in respect to light, therefore it would cease to exist. But the **nothing** is **nonexistent**.

- According to **Maxwell's equations for the propagation of electromagnetic waves**:

     1) The **universe** is not empty but it is **filled** with the stationary ether.

2) The **electromagnetic waves travel** with the **speed of light, c, relative to the ether's rest frame**. If an **observer** is moving at a speed, u, relative to the ether, the speed of light emitted by a source at rest relative to the ether would be **c+u** if the observer were moving toward the source, and **c-u** if the observer were moving away from the source. The **ether** is the **matter**, the **energy**, and the energy **fields** that fil and transverse **space** and **time**. **Empty space**-absolute vacuum, **does not exist**.

- For **real gases**, the Van der Waals equation ¾$[P + a(n/V)^2][(V/n - b)] = RT$, where a and b are positive constants ¾ states that the attractive component of the intermolecular force acts to make a gas more compact. This translates into reduced pressure, and the $a(n/V)^2$ term represents the **pressure reduction** due to **attraction** between molecules. The term b represents the strong **repulsion** between molecules at a characteristic radius, and is a measure of **volume unavailable** for motion.

- Under **high pressure**, change of position, that is **translation, rotation** and **vibration** of atoms, is negligible to nonexistent, and the **heat capacity of the system is very low**.. The electronic energy level involves great amounts of energy, the compression of electron shells and the flow of electrons and of other particles, that is **high electrical conductivity**.

- **Thermal energy**, that is, in increasing order, **translational**, **rotational** and **vibrational energy** is only a **very small fraction**, from 10^{-6} to 10^{-2}, **of electronic energy**.

- The **binding energy** between **atoms** is of the order of eV, while between **nucleons** is of the order of MeV, that is about 10^6 times greater. **Iron** has the **highest binding nuclear energy, 8.8 MeV per nucleon**, from all elements, and **hydrogen the lowest, 1.1 MeV per nucleon**.

- The **gravitational force** between a proton and an electron is only $\sim 4'10^{-47}$ N, while the **electric force** is $\sim 9'10^{-8}$ N, that is $\sim \mathbf{10^{39}}$ **times greater** than the gravitational force.

- The **electric force** is behind **friction** and other **contact forces**.

- The **size** of a mineral is of the order of 10^{-5} m, of an atom 10^{-10} m, of a proton and a neutron 10^{-15} m and of an electron less than 10^{-18} m.

- The **mass** of a nucleon (proton or neutron) is about $1.67'10^{-27}$ kg and that of an electron $9.1'10^{-31}$ kg.

- The **electric charge** of an electron and of a proton is - $1.6'10^{-19}$ and +$1.6'10^{-19}$ Coulomb, respectively.

- **Tunneling**, that is the crossing of a potential barrier, can occur either by **increasing the kinetic energy** of particles through heating, at 10^6 to 10^9 degrees, and/or by **lowering the barrier height** by applying an external electric potential, i.e., van der Waals dielectrics, and/or by **decreasing the barrier width**, at 10^{-8} to 10^{-9} m, through pressure. For **fusion** of H nuclei to occur a pressure of the order of 10^{26} Pa is required.

- For **two protons** that **fuse** with two ^{2}H nuclei to form two ^{3}He nuclei, that in turn fuse to produce one ^{4}He nucleus, **two protons and 24 MeV are produced.** (2^2H + 2**p** ® 2^3He + 2g + 11 MeV ® ^{4}He + 2**p** + g + 13 MeV)

Hydrogen and Helium Nucleosynthesis

$$(2\ ^2H + 2p \circledR 2\ ^3He + 2g + 11\ MeV \circledR \ ^4He + 2p + g + 13\ MeV)$$
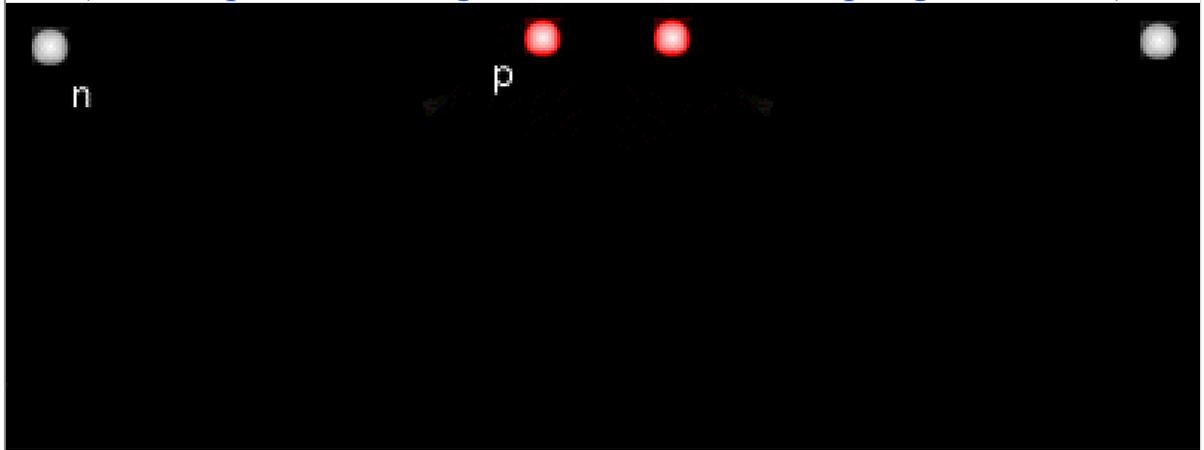
Animation by David Ford

- **Van der Waals attractive forces** $(1/r^5)$, are weak when compared to **coulombic attractive forces** $(1/r^2)$, develop when **atoms without electrons outside closed shells** acquire **polarity** and form molecules with a subsequent **contraction-condensation** and reduction in pressure, i.e., **helium molecules (He_2)**.

- **Dipoles** are formed when **two equal point** electric charges **- electric dipoles** or magnetic poles **- magnetic dipoles** of opposite sign **do not coincide**, and are separated by a small distance.

- **Electric and magnetic dipoles produce a field** and **respond to a field**.

- **Dipole moment** of a particle is the product of either charge or pole and the distance between the two. It is a measure of its electrical and/or magnetic **asymmetry**.

- **Polarity** can be **intrinsic** or **induced** as a result of **external electric field and/or pressure**. For that matter attractive forces, due to polarity, can develop among any polar-spinning particles, i.e., between nucleons.

- The greater the **pressure** the greater the **polarizability** of particles.

- **Dipole** orientations favor the **attractive low potential energy** over the **repulsive high potential energy**.

- **Van der Waals forces** that develop between dipoles themselves and between dipoles and the walls of a confining material, are **much stronger than the force of gravity** (i.e., $\sim 10^{36}$ times) and they can move the polar atoms against gravity.

- **Capacitors** are a pair of conductors with equal but opposite charges separated by empty space or by a non conducting material, i.e., dielectric.

- **Dielectrics**, that is **polar atoms** attracted by van der Walls forces, behave as **insulators**, that is the net electric field inside the dielectric, E, is equal to the external electric field, E_0, minus the induced electric field, E_{ind}, $E = E_0 - E_{ind}$. If E_{ind} were to exceed E_0, that is the dielectric-insulator to become a **conductor**, due to the addition of electrons in outer shells, the electric field inside the dielectric will be reversed.

- **Dielectric** and **diamagnetic substances** develop an induced electric and magnetic field, opposite to the direction of the inducing electric or magnetic field, respectively. They behave as **electric and magnetic insulators**. For example, **inert gases** such as helium, neon and argon but also **iron** with filled the 3d-level with 10 electrons.

- The **electrical conductivity** of an **insulator** (i.e., glass) is from 10^{-14} to 10^{-10} (ohm-meters)$^{-1}$, of a **semiconductor** (i.e., silicon, carbon) from 10^{-3} to 10^{5} (ohm-meters)$^{-1}$, of a **conductor** (i.e., iron, aluminum, copper, silver) from 10^{7} to 10^{8} (ohm-meters)$^{-1}$ and of a **superconductor** over 10^{8} (ohm-meters)$^{-1}$.

- The estimated **electrical conductivity** ranges from **$\sim 10^{-2}$ in the surface**, to **$\sim 10^{-3}$ in old shields**, to **~ 1 in young oceans**, to $\sim \mathbf{10^{2}}$ (ohm-meters)$^{-1}$ at the core-mantle boundary.

- A **superconductor** behaves as **diamagnetic material**, that is **no magnetic field can penetrate it**.

- Inside a **Type I superconductor** the electric and the magnetic resistivities **are zero**, that is the **electric and the magnetic fields inside it are zero**.

- Inside a **Type II superconductor** the electric and magnetic resistivities **are not zero**, that is the **electric and the magnetic fields inside it are not zero**, but **they are zero on its surface**. In that case **all current carried by a superconductor is carried on its surface**, which represents the **boundary** between the superconducting and the nonsuperconducting phase of the material.

- An electron in an atom moves with a **speed** of the order of 10^{6} m/sec, while a free electron in a TV tube travels with a speed of $7' 10^{7}$ m/sec.

- **Experimental values** show and **quantum physics** predicts that:

    a) The **mean free path** to be about two orders of magnitude greater, and the **mean collision time** about one order of magnitude longer and the **average speed** one order of magnitude greater than the **free-electron**, temperature dependent, classical prediction.

    b) **In a perfectly ordered crystal with no impurities, at the temperature of zero, there would be no resistance to electron flow, and conductivity would be infinite**.

- **Electrical conductivity** is **inversely proportional to temperature**, that is to the increased vibration of

lattice atoms and **proportional to pressure**.. Even in semiconductors, tunneling and, therefore, increase in conductivity can occur by narrowing the energy gap by compression and/or by applying a modest electric field and only in a low pressure environment heat can excite electrons and ions.

- **Angular momentum**, $L = Iw$, of a particle is the product of **moment of inertia, $I=mr^2$,** and **angular velocity**, $w = u/r$, has the dimensions of **action** (energy-work ´ time), $kg.m^2.s^{-1}$.

- **Planck's constant**, $h = 6.63´10^{-34}$ **J.s,** relates the **frequency** of radiation, **f,** with its **quantum of energy, E;** i.e., **E = hf.** It has the dimensions of action , that is of **angular momentum**.

- **Quantum numbers** are **integral** or **half-integral** multiples of h/2p that specify the energy state of a system in **quantum mechanics**. An electron has four quantum numbers.

    a) The **principal** quantum number**, n = 1,2,3 ,...,** defining the energy level or shell in which the electron occurs,

    b) The **azimuthal** quantum number, **l = 0, 1, 2, ..., n-1,** defining the shape and the multiplicity of the orbit within that shell,

    c) The **magnetic orbital** quantum number, m_0 = **-l -l +1,..., 0,..., l -1, l,** which determines the orientation of the orbit, with reference to a strong magnetic field, and,

    d) The **magnetic spin** quantum number, m_s = ± ½ , which determines the direction of the spin of an electron in a magnetic field. The + or - stand for clockwise or anticlockwise direction of rotation or spinning, respectively.

- The **angular momentum** of a particle has two components. The **orbital** (**n** and **l**-magnitude, and **m**-direction) and the **spinning** (**s**-direction).

- The **orbital magnetic dipole moment, m_0 = m_bl ,** can have values that are integral multiples of Bohr magneton, m_b = **eh/4p m_e** .

- **Magnetic field lines**, that is the magnetic dipole moments, form circles around the moving electric charge or current in a plane perpendicular to the moving charge or current.

- **Magnetism** in mater is due ultimately to the magnetism of its atomic constituents, and particularly to the **unpaired electrons of atoms**.

- If two orbiting electrons have **opposite directions**, i.e., clockwise-anticlockwise, the orbital magnetic dipole moment, in the absence of an external magnetic field, is **zero**.

- **The zero (0,‾) spin state**, due to the **attractive forces** between particles with spins in opposite directions, is a **low energy state**.

- **The unit (+1, -1‾)spin state**, due to the **repulsive forces** between particles with spins in the same direction, is a **high energy state**.

- Particles with unit spin can be oriented along any applied field to give the three states with quantized integral spin components, i.e., +1(), 0(‾), - 1(‾).

- The **nuclear spin quantum numbe**r can be 0 or integral or half-integral number.

- **Bosons** are particles with total spin **zero** or **integral multiple** of h/2p : $I_{b(h/2p)}$**), where I_b= 0, ± 1, ± 2, ± 3,...± n.**

- **Fermions** are particles with total spin **half-integral multiple** of h/2p : $(I_b+ \frac{1}{2})(h/2p)$.

- The **Pauli exclusion principle** states that only **one boson** with identical zero or integral spin and only **up to two fermions** with identical half-integral spins, **can occupy the same energy state,** i.e., have the same n, l and m_o quantum numbers.

- According to **Heisenberg's uncertainty principle** in any **quantum phenomenon** (particle - wavelike phenomenon) at any given time it is **impossible to know precisely both the position and the speed-momentum of the particle.**

- **Identical bosons** tend to congregate in the same, lowest possible, energy state. This can explain **laser-maser** (Light/Microwave Amplification by Stimulated Emission of Radiation) and **superfluidity**.

- **Pairs of identical fermions**, i.e., electrons, can form bosons with a net angular momentum of 0 or integral multiple of h/2p , and behave like a large system of *identical bosons*. That is the microscopic explanation of **superconductivity**.

- **Incompressibility** is a result of **repulsive forces** (coulombic and between **identical fermions**, i.e., electrons). Measure of incompressibility is the *bulk modulus* (N/m^2), that is the ratio between volume stress and volume strain (PV/dV).

- **Compressibility** is a result of **attractive forces** that develop between **identical bosons** as well as of coulombic attraction. Measure of compressibility is the negative (contraction due to attraction) reciprocal of bulk modulus(m^2/N).

- **Degeneracy pressure**, P_e , is the **outward** directed pressure, due to electrons. It is another expression of the **incompressibility of matter**. It is calculated according to the formula:

$$P_e = (3/5)[(h/2p)^2/ (2m_e)] [(3p^2)^{2/3}] [(N_e/V)^{5/3}]$$

where N_e the number of electrons, and m_e the mass of an electron.

- **Gravitational pressure**, P_g , is the **inward** directed pressure, due to neucleons, that acts to **compress matter**. It is calculated according to the formula :

$$P_g = 0.32[G(N_nM_n)^2 / V^{4/3}]$$

where N_n number of nucleons, M_n mass of nucleons.

- **Resonance** is the result of **congregation of identical bosons and/or of pairs of fermions.**

- **Shock waves**, that is a **very narrow region of high pressure and energy**, are produced whenever **wave sources**, i.e., electrons, protons, a-particles, **can move faster than the waves they produce**. The **higher the speed** of the particle, the sharper the cone of the shock wave (q_0®90^0) that tends to become a line and, therefore, the **higher the pressures** in the medium and the more abrupt the change in that. A **proton** travelling with a speed of the order of $3´10^7$ **m/sec** produces **shockwave pressures** of the order of 10^{30} **Pa.**

- **Superconductivity**, that is **the pairing of fermions into bosons**, i.e., pairing of electrons, as far apart as 10^{-7}m, that is about 10^{11} times their size, occurs because of the presence of other pairs in the same energy state. **Pairs condense, and behave as one coherent 'solid' state, when ion lattices can not vibrate, as a result of low temperature and/or high pressure.**

- **^{4}He atoms**, are **bosons** with 0 angular momentum for the nucleus (two protons and two neutrons) and 0 or integral multiple of h/2pfor the two electrons ($\pm 1/2$, $\pm 1/2$). Therefore they are subject to the exclusion principle and they condense into a coherent state. They exhibit **superfluidity**, that is they flow as if they have **no internal friction** (no viscosity).

- For a given potential energy of a particle, **the smaller the region in space** that is made available to the particle, that is the higher the pressure, **the higher will be the kinetic and, therefore, the total energy of the particle.**

- The **core** of the Earth can be considered as a **real gas of particles**, particularly of electrons, protons and a-particles, **subject to the exclusion principle**. The real gas character is mostly due to polarity and to the attractive, van der Waals forces, that tend to make them cluster. The volume occupied by the particles is negligible and, therefore, the excluded volume correction is also negligible. On the other hand the **pressure reduction correction**, due to clustering, is very important, resulting into a considerable contraction-reduction in volume.

- **Plasma** is matter dissociated into positively and negatively charged particles, and it is considered as the fourth state of matter.

- There are three **fundamental forces**:

  1. **Gravity** that refers to bulk matter,

  2. **Weak Force** that includes all **electromagnetic type forces** and refers to the atomic level, and,

  3. **Strong Force** of the nuclear level.

- **On all but the astronomical scale, atomic and nuclear forces are much stronger than gravitational forces.**

- So far a theory that unifies **gravity mechanics-general relativity** and **quantum mechanics-uncertainty principle** has not been found.

Some cognitive tools from Geology and Geophysics:

- **60 to 65% of the Earth's surface** is covered by **oceanic crust**, that is **rocks mafic in composition and younger than 200 m. y.**

- **35 to 40% of Earth's surface** is covered by **continental crust**, that is **rocks intermediate to felsic in composition and up to 4 b.y. old**.

- The composition and the age of rocks in other planets, i.e., **Moon, Mars, Mercury, meteorites**, is similar to rocks of the **continental crust** of the Earth, that is, they are iron poor and about 4 b.y. old. Iron rich rocks are scarce and are much older than 200 m. y.

- The **northern hemisphere** is about 2.5 km higher than the southern hemisphere. As a result its moment of inertia is greater by 0.03%, or by $1.25'10^{40}$ gr/cm^2 and it is **lagging westward relative to the**

southern hemisphere (Tethyan Torsion).

- Isotope composition of most **granitic batholiths** indicates an **origin in the lower crust or upper mantle**.

- The **geothermal heat loss** of the Earth is of the order of 3×10^{13} **W per year**.

- The **heat flow** from both continental and oceanic areas is of the order of **1.5 - 2 m cal/sec/cm^2 (HFU)** or $60 - 80 \text{ mW/m}^2$.

- The **concentration of ^{232}Th and ^{238}U** in the Earth is 65 and 18 ppb, respectively.

- Almost all **radioactive elements** are concentrated at the **upper few kilometers** of the Earth's **continental crust**.

- The concentration of radioactive elements in the **Moon** is about **three times** greater than in the **Earth**.

- The **gravitational field** of the Earth is about 980 gals $\pm$ 0.5%.

- **Gravity fluctuations** are usually of the order of few mgals to few hundred mgals $= 10^{-6}$.

- **Bouger gravity anomalies** measure **past or present density differences** from an **assumed average density** for a given area.

- **Free-air gravity anomalies** measure **contemporary or very recenttopographical differences -uplift**, i.e., differences between the geoid and the sheroid-ellipsoid.

- The **electric field** on the Earth's surface is of the order of -10^2 Volts/meter (Newtons/Coulomb).

- The estimated **potential difference** between the surface of the earth and the mantle-core boundary is 290×10^6 Volts.

- The assumed **electric field at the mantle -outer core surface** is of the order of -10^{31} V/m. That corresponds to a charge of $\sim10^{53}$ electrons.

- The assumed **electric field at the outer core-inner core boundary** is of the order of $+10^{29}$ Volts/meter. That corresponds to a point charge of about 10^{50} protons in the inner core.

- The assumed **potential difference between the mantle-outer core boundary and the outer core-inner core boundary** is of the order of 2×10^{37}V.

- Almost all **rock-forming minerals** are compounds which have **mixedionicandcovalent bonding** and they are fundamentally **electrical insulators**, with conductivity, in their pure 'dry' crystalline form, of the order of 10^{-12} to 10^{-17} mhos/m.

- **Moisture and water** in minute cracks can conduct electricity by electrolytic transport and **increase the conductivity** of 'dry' crystals up to 10^{11} times.

- **Metallic minerals**, that is minerals that share the outer electrons of the metallic atoms, i.e., pyrite

(FeS_2), pyrrhotite (FeS), galena (PbS), graphite (C), etc., have conductivities that range between 10^2 and 10^6 mhos/m.

- **Native metals**, i.e., iron, copper and silver, are excellent conductors, with conductivities $5'10^6$, $5.8'10^7$ and $6'10^7$ mhos/m, respectively.

- The **Earth is a weak magnet** and the strength - **intensity of its magnetic field**, 0.35 - 0.65 oersted (~9 to 16 Amp/m), corresponds to a **magnetic dipole of moment** $8'10^{26}$ emu or $2'10^{22}$ Amp/m^2 , of a magnet which is situated close to its center and is inclined at about 11^0 to the geographical axis.

- The **magnetic flux density** is about 0.5 Gauss (in S.I. units $0.5'10^{-4}$ Tesla).

- The practical unit for measuring **magnetic field strength** is the g (gamma) = 10^{-5} oersted.

- The **average magnetic intensity** is about 50,000 gammas. The maximum polar intensity is 65,000 gammas and the minimum equatorial intensity 35,000 gammas.

- In a number of cases **magnetic anomalies** having amplitude higher than 100,000 gammas have been recorded on the ground over magnetite deposits. That is **up to three times the amplitude of the Earth's magnetic field**.

- **All** materials are **diamagnetic**, that is when placed in a magnetic field they will acquire a **small magnetic moment which is in a direction opposing the field**. The diamagnetic effect is, in fact, **temperature independent** and is a function of the quantum numbers of the electrons, i.e., it depends on the nature of the **electron orbitals**..

- **Many** materials are also **paramagnetic**, that is when placed in a magnetic field they will acquire **magnetization which is proportional to, and in the same direction as the external field**.

- **Truly ferromagnetic** are those materials that the **magnetic moments of all the ions in the lattice tend to point in the same direction**, i.e., metallic iron, nickel, cobalt.

- In **ferrimagnetic** materials **some of the moments tend to lie in a direction different to opposite from that of the others**, i.e., **magnetite (Fe_3O_4)**.

- **Antiferromagnetic** is a special case of **ferrimagnetic material**, whereby **the ions of the lattice are divided into two exactly equivalent groups, which are magnetized in opposite direction**, i.e., **hematite (Fe_2O_3)**.

- **Magnetic susceptibility** is the ratio of intensity of **magnetization** produced in a substance to the strength of the **magnetic field** to which it is subjected.

- At **multidomain** grains, and for grain sizes **bigger than ~10^{-5} m**, i.e. Fe_3O_4, the **magnetic susceptibility increases with increasing size**.

- For **grain sizes smaller than about 10^{-5} m and bigger than about 10^{-6} m**, the **magnetic susceptibility decreases with decreasing grain size**, i.e., the smaller the size, the weaker the induced magnetization by a given external field and the stronger the residual magnetization when that field is removed.

- In **monodomain** grains, and for **grain sizes less than 10^{-6} m**, the **magnetic susceptibility increases**

with decreasing size while hysteresis effects diminish. A material at such stage is said to be **superparamagnetic**.

- In monodomain grains the **energy barrier**, between the different directions in which the magnetization is stable, is **high**. Therefore a **strong field** is required to produce change, and once changed, the magnetization does not easily return to its original state.

- The **magnetic susceptibility** of mafic rocks, i.e., basalt, is about $3'10^{-3}$ emu, while of felsic rocks, i.e., granite, is about $0.5'10^{-3}$ emu.

- The **magnetic flux density** of an electron that moves with a speed of 10^7 m/sec at the mantle-core boundary and around the inner core, where about 10^{50} protons are present, is of the order of 10^{21} Tesla.

- **Magnetic reversals** need a few thousand years to happen and, on the average, they last about 500 thousand years.

- **Moon, Mars and Mercury have very weak remnant or no magnetic field.**

- An **increase of radius and/or of mass** in a zone of a spinning body will result to an increase of its moment of inertia ($I = m.r^2$) and consequently of the **centrifugal force - torque** ($F = t = I.a = m.r^2.v^2/r = m.r.v^2$) of that zone which will tend to become equatorial.

- **Orogenic episodes** reached their maximum intensity at **2600**, **1800**, **900** (Cordilleran), **500** (Caledonian-Hercynian), and **100** (Alpine) million years ago.

- The non-elastic **brittle** deformation is **rapture-faulting**, and the non-elastic **ductile** deformation is **flow-folding**.

- The **faulting in the crust** is, in general, **normal**. It is a result of **tensional fracture** at the surface and **shear fracture** at greater depths.

- In **normal** faults the **maximum principal stress is vertical**, i.e., gravity.

- At the **flanks of domed-deformed areas**, the faulting is **reverse**.

- In **reverse** faults **gravity is the minimum principal stress**.

- In **strike-slip** faults **gravity is the intermediate principal stress**.

- In **oblique-slip** faults **none of the principal stress axis is vertical**.

- In **Benioff zones** the faulting is **reverse** and **oblique**.

- Brittle-plastic substances, when their strength is not exceeded, undergo **cataclastic flow-transient creep,** which results to deformation up to ~1% and it is due to repeated shear fractures which progressively reduce the grain size, or to the rolling and sliding of fragments over one another.

- **Ductile deformation**, that is **flow**, occurs when the strength of a **brittle-plastic substance** is exceeded or when the substance has **low viscosity**, i.e., it is **fluid**. It can be:

  a) a low temperature **plastic flow**, in which gliding motions on intersecting planes occur, and the material behaves as a **plastic-brittle** substance.

b) **power-law flow** or creep, caused by motion on dislocations which take up a polygonal cellular pattern within the grains, and

c) **diffusion creep**, caused by migration of atoms in a stress gradient, occurring within the crystal lattices or along grain boundaries.

In all cases the **flow** can be **temperature independent** and **pressure dependent**.

- In **passive folds**, the **viscosity** of each layer is the **same** or nearly the same, and each layer has a similar folded form.

- **Flexural-slip folds** commonly become detached, due to differences in viscosity, along some surface at depth, called the **décollement zone**, which is a **low viscosity zone**.

- A **Newtonian fluid** is a **viscous fluid** in which the **viscous -shear stress, t** (gr/cm.sec^2 or **kg/m.sec^2**), is a multiple of the **rate of strain, (DL/L)/dt - velocity gradient, du/dy** (sec^{-1}), and of the constant of proportionality, that is the fluid **viscosity, m** (gr/cm.sec, or **kg/m.sec) [t= m (du/dy)]**.

- In a **non-Newtonian, visco-elastic, fluid** the shear stress depends not only on the **velocity gradient**, but also on the **strain**.

- A **plastic-brittle** material exhibits an apparent yield stress (**t**). In other words it behave as a **solid**, that is its **strain rate is very low** and remains low as the shear stress increases until it **yields** and as the shear stress further increases, it behaves like a **viscous fluid**, that is for low shear stress its **strain rate is very high**.

- **Superplastic** flow occurs when there is a significant concentration of a mineral phase of **very small grain size**, i.e., of atomic dimensions.

- A **dilatant-ductile** material behaves as a **low viscosity** fluid at low stress and strain rates, but as **solid** as the stress and strain rate increase.

- In a **Stress Engine Earth** the interior of the Earth, i.e., the **mantle**, behaves like a **plastic-brittle material**, while in a **Heat Engine Earth** as **dilatant-ductile material**.

- The **strain-creep rate,** that is **the velocity gradient inside the Earth** is of the order of **10^{-15} sec^{-1}**, that is a velocity of flow of the order of few centimeters per year and a boundary layer of the order of 100 to 1000 km, whereas the slowest rates attainable **in experiments** is only about **10^{-8} sec^{-1}**, that is about 10^7 times faster.

- Experiments show that for **pressures above ~0.5 GPa**, that is for depths greater than ~20 km, and for **temperatures above 770 K**, that is above 500 ^{0}C, **no brittle deformation**, that is no sudden fracture, occurs.

- The **strength of brittle materials increases with the increase of the confining pressure** but **decreases with rise of temperature**.

- The **strength of ductile materials decreases with the increase of the confining pressure and of the temperature**.

- At **atmospheric temperature and pressure** the **tensile strengthof granite is ~10^6 Pa**, while its

compressive strength is ~$1.4'10^8$ **Pa**.

- **Tensile strength** of rocks in the **mantle** is of the order of 10^{10} **Pa**, while the **compressive strength** is of the order of 10^{11} **Pa**.

- The **rigidity** and the **incompressibility** of rocks in the crust is estimated to be of the order of $5'10^{10}$ and 10^{11} Pa, in the upper mantle 10^{11} and $2'10^{11}$ Pa, in the lower mantle $2.5'10^{11}$ and $5'10^{11}$ Pa, in the outer core 0 and 10^{12} Pa, and, in the inner core $1.8'10^{11}$ and $1.5'10^{12}$ Pa, respectively.

- The **viscosity** of rocks inside the Earth is estimated to be from 10^{20} to 10^{27} poises.

- The **relaxation time** (viscosity/rigidity) for rocks inside the Earth is of the order of 10^9 to 10^{15} sec, that is of the order of tens of years to tens of million years.

- The **duration of applied stresses** inside the Earth is from **less than 1 second** to **over 10^{16} seconds**, that is billion years.

- In island arcs the **potassium content increases proportionally to the depth of the Benioff zone**.

- The **Q factor** for P and S waves in the crust and in the upper mantle is estimated to be of the order of 300 - 400 and 100 - 150, in the lower mantle 5000 and 2000, in the outer core 10000 and 0, and, in the inner core 900 and 500, respectively. In other words, in the **outer core**, the **attenuation is extremely low for P waves and extremely high for S waves**.. In the lower mantle attenuation is very small for both P and S waves, while in the upper mantle and in the crust is relatively high.

- When the **dimensions of flow are equal or greater than the length of seismic waves**, mainly of S waves, that transverse the flow, the seismic waves can 'see' and 'feel' the flow and the peak or the valley of the wave that has the same direction with the flow is absorbed by it, thus increasing the rate of flow and, consequently, the **attenuation**.

- **Temperature** increase can **increase attenuation** by **decreasing resistance to flow**.

- The **velocity of P and S waves** in the **upper mantle** is estimated to be of the order of **8 and 4.5 km/sec**, in the **lower mantle 12 and 5 km/sec**, in the **outer core 10 and 0 km/sec**, and, in the **inner core 11 and 3.5 km/sec**, respectively.

- The **average density** of the **crust is ~2.8 gr/cm^3**, of the **mantle ~4.5 gr/cm^3** , of the **core ~10.7 gr/cm^3**, and of the **whole Earth ~5.5 gr/cm^3**.

- The **pressure** at the **crust - mantle boundary** is of the order of 10^9 **Pa**, at the **mantle - core boundary is ~$1.4'10^{11}$ Pa**, and, at the **center of the Earth ~$3.7'10^{11}$ Pa**.

- The **variation with depth of seismic wave velocities, of density, and of pressure** is known with a **degree of confidence of 95%**.

- The variation of **temperature with depth**, for depths greater than about 10 km, is **not directly known**.

Answers (?) to questions:

- The dominant character of processes inside the Earth is **irreversible**.

- The irreversibility is **upgrading**.

- The upgrading irreversibility is a result of **many episodes.**

- The Earth, except for a thin surface layer, is a **Stress Engine**--that is, an **electrically unbalanced 'real gas' of particles subject to the exclusion principle.**

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Acknowlegement

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