COVENANT UNIVERSITY
NIGERIA

TUTORIAL KIT
OMEGA SEMESTER

PROGRAMME: PHYSICS

COURSE: PHY 226

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PHY 226: Physics of the Solid Earth
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1. Explain the two models commonly used to explain the universe.

2. State Kepler's laws of planetary motion.

3. State the law of universal gravitation

4. What are the prominent features of the solar system?

5. What is meant by lithospheric plates? Distinguish between constructive and destructive plate margins.

6. Write short notes on the shape and size of the earth.

7. Distinguish between the Nebular and Collision hypotheses, highlights their relative strengths and weaknesses.

8. Explain what is meant by continental drift? Discuss any two hypotheses that explained the dynamic condition of the Earth interior.

9. Discuss, illustrating with diagrams, the radial structure of the Earth's interior.

10. What is meant by geoid undulation? Give reasons why the geoid and the International Reference Ellipsoid are not in agreement.

11. State the factors responsible for the increase in gravity towards the pole.

12. Distinguish between seismic body and surface waves. Show analytically that the velocity of P-waves is always greater than that of S-waves in all propagating media.

13. Discuss the factors responsible for the attenuation of seismic waves in a typical earth media.

14. How would you locate the epicentre and exact location of an earthquake if the travel times of P-waves and S-waves are recorded at any observation station?

15. What are the possible sources of heat flow in the Earth's interior?

16. Discuss the mechanism of electrical conduction in the subsurface.

17. State and explain the various methods used in palaeomagnetic analysis.

18. Write concisely on the following: Magnetic susceptibility and apparent polar wandering.

19. What is remanent magnetization?

20. What do you understand by isostasy? Discuss the models that explain the theory of isotasy.

SOLUTION

1) Geocentric (earth centred) model and heliocentric (Sun centred) model

3) The force of attraction between a planet and the Sun varied with their masses and with the inverse square of the distance between them. Applying this law to two point masses m and M separated by a distance r, the gravitational attraction F exerted by M on m is: $F = -G\dfrac{mM}{r^2}\hat{r}$ where $\hat{r}$ is a unit vector in the direction of r and G is the constant of universal gravitation with value $6.6725985 \times 10^{-11} m^3 kg^{-1} s^{-2}$. The negative sign indicates that the force acts in opposite direction towards the attracting mass M.

5) Tectonic plates are not crustal units but involve the entire thickness of the lithosphere of which the crust is only the outer skin. The lithospheric plates move relative to each other across the surface of the globe. Hence, continental drift is a consequence of plate motion. The lithospheric plates are very thin when compared to their breadth (i.e. their thicknesses are much less than their lengths). Most earthquakes occur at the plate margins, and are associated with the interactions between the plates. The plate interiors are *aseismic* (not seismically active), though intra-plates earthquakes may occur and could be as large and disastrous as those at the plate boundaries. This suggests that tectonic plates behave like a rigid body. Three types of plate margins can be distinguished by different tectonic processes.

Constructive (or Divergence) Plate Margin: The world-wide earthquakes pattern shows that the plates are currently moving apart at oceanic ridges. From magnetic evidence, the separation has been on for millions of years. New lithospheres are being formed at these spreading centres, and hot molten materials ascend to plug the gap left by the lithospheres moving away from each other. An example of constructive plate margin is the mid Atlantic ridge. The gap between the South America and Africa is now about 5,500 km.

Destructive (or Convergence) Plate Margin: Sometimes the lithospheres are pulled towards each other and this process is called *subduction*. One plate is forced under another, and because it is thin in relation to its breadth, the lower plate bends sharply before descending to depths of several hundred kilometres were it is absorbed. An example is the south-eastern margin of the

Pacific Ocean. The friction produces subduction which usually results in severe earthquakes such as those that occur in the western side of South America, Andes, Japan, California and Lose Angeles. Another feature of subduction is that thick sediments that have been accumulated along the continental edges are sometimes rucked up to form Fold Mountains. The Himalayas Mountain and several mountain ranges were formed this way. Such a folded sedimentary mass is called *orogen* and this process of mountain formation is known as *orogency*.

7) **Nebular Hypothesis**: This hypothesis states that planets and their satellites were formed at the same time as the Sun; space was filled by a rotating cloud (*nebula*) of hot primordial gases (mainly hydrogen and helium) and dusts that, as it cooled, began to contrast. Its rotation speeded up so as to conserve angular momentum and centrifugal force caused concentric rings of matter to be thrown off, which then condensed into planets. A major objection to this hypothesis is that the mass of materials in each ring would be too small to provide the gravitational attraction needed to cause the rings to condense into a planet. Also, as the nebula contrasted the largest part of the angular momentum would remain associated with the main mass condensed to form the Sun. But this disagrees with the observed distribution of angular momentum in the solar system.

Collision Hypothesis: This hypothesis assumed that the Sun was formed before the planets. The gravitational attraction of a closely passing star or the blast of a nearby exploding *supernova* (a star that suddenly becomes brighter as it is exploding) drew out a filament of solar materials that condensed to form the planets. The flaw in this hypothesis is that the solar materials would have been so hot that it dissipated explosively into space rather than slowly condensing to form the planets.

9) The study of seismic waves indicates that the Earth's interior has a radially layered structure like that of an onion or a baked cake. The boundaries between the layers are marked by abrupt changes in seismic velocity or velocity gradient. Each layer is characterized by a specific set of physical properties, which is determined by the composition, pressure and temperature in the layer. The Earth's interior can simply be grouped into four main layers: the crust, mantle, outer core and inner core. The radially layered model of the Earth's interior assumes spherical symmetry and this is, however, not valid for the crust and upper mantle. These outer layers of the Earth show important lateral variations. The crust and the uppermost mantle down to a depth of

about 70 – 100km under deep ocean basins and 100 – 150km under continents is rigid, forming a hard outer shell called the lithosphere, which is relatively cool and brittle. The crust makes up the bulk of the continental lithosphere whereas the uppermost mantle makes up the bulk of the oceanic lithosphere. Thus the oceanic lithosphere is more dense than the continental lithosphere. Oceanic segments or plates will therefore descend beneath the continental crust if collision occurs.
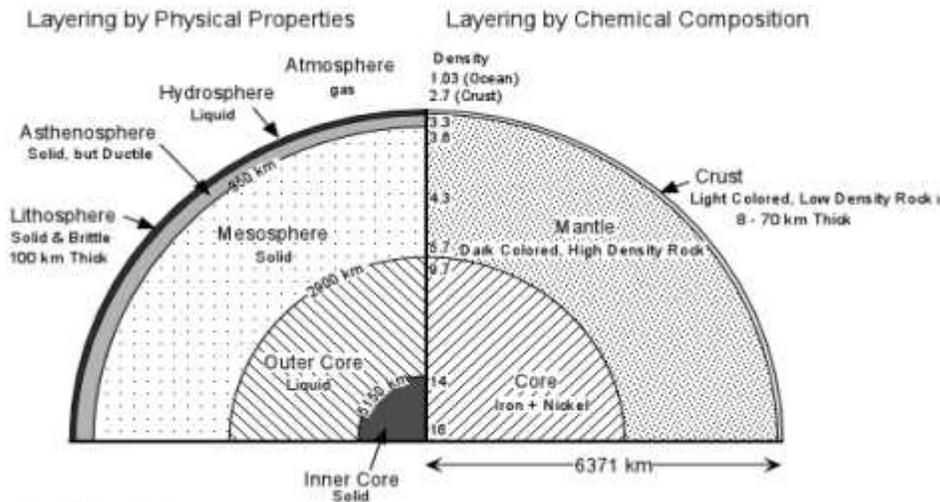

Figure 1.4: Simplified layered structured of the Earth's interior.

Beneath the lithosphere lies the asthenosphere which is about 150km thick, hot, weak and partially molten. Its upper and lower boundaries are not sharply defined. Seismic velocities usually decrease while propagating through this region suggesting that the asthenosphere is of lower rigidity when compared with the lithosphere. The asthenosphere is sometimes called the low velocity zone. It plays an important role in plate tectonics because it makes possible the relative motions of the overlying lithospheric plates.

11) The pole-ward increase of gravity is attributed to the following:

i.   The distance to the centre of mass of the Earth is shorter at the poles than at the equator. This gives a stronger gravitational acceleration, a_G at the poles with an excess gravity of about 6600mgal at the poles.

ii.   The diminishing effect of the centrifugal force on gravity is largest at the equator, where it is ma_G and zero at the poles. This results in pole-ward increase of gravity of about 3375mgal.

13)   The further a seismic wave travels from its source the weaker it becomes. The decrease of amplitude with increasing distance is known as attenuation. It is partly due to the geometry of propagation of seismic waves, and partly due to inelastic properties of the medium through which they pass. Consider the seismic body waves generated by a seismic source at a point P on the surface of a uniform half space. If no energy is lost due to friction, the energy E_b in the wave-front at a distance r from its source is distributed over the surface of a hemisphere with area $2\pi r^2$. The energy density or intensity I_b is $I_b(r) = \dfrac{E_b}{2\pi r^2}$.

For seismic surface waves, the disturbance affects not only the free surface but extends downward to a depth d. When the wave-front of a surface reaches a distance r from the source, the initial energy E_s is distributed over a circular cylindrical surface with area $2\pi rd$ such that the energy density becomes $I_s(r) = \dfrac{E_s}{2\pi rd}$.

These equations shows that the decrease in energy density of the body waves is proportional to $\dfrac{1}{r^2}$ while the decrease in of surface wave energy density is proportional to $\dfrac{1}{r}$. But the intensity of a wave-form, or harmonic oscillation, is proportional to the square of its amplitude. Hence, the corresponding amplitude attenuations of body waves and surface waves are proportional to $\dfrac{1}{r}$ and $\dfrac{1}{\sqrt{r}}$, respectively. Seismic body waves are therefore attenuated more rapidly than surface waves with increasing distance from the source. Seismic waves are also attenuated as a result of the absorption of energy due to imperfect elastic properties. This type of attenuation is called inelastic damping. The damping of seismic waves is described by a parameter called the quality factor, Q which is defined by the relation: $\dfrac{2\pi}{Q} = -\dfrac{\Delta E}{E}$, where E is the total energy stored in the

wave and ΔE is the energy lost in a cycle. If the damping is considered as a function of the distance that the seismic wave travels, the above equation can be written as: $\dfrac{2\pi}{Q} = -\dfrac{\lambda}{E}\dfrac{dE}{dr}$. Thus

$$\frac{dE}{E} = -\frac{2\pi}{Q}\frac{dr}{\lambda}$$

15) Radioactivity

17) The various methods used in palaeomagnetic analysis include:

   i.   Measurements of remanent magnetization with the aid of spinner magnetometer or cryogenic magnetometer.

  ii.   Stepwise progressive demagnetization. The natural remanent magnetization (NRM) of a rock may contain several undesirable components. It is necessary to "magnetically clean" the natural magnetization so that the structure NRM can be analyzed and isolated. This is done by stepwise procedure, in which progressively more and more of the original magnetization is removed. This can be achieved by using either progressive alternating field demagnetization or progressive thermal demagnetization.

 iii.   Analysis of magnetization components. The stability of a remanent magnetization during stepwise demagnetization can be demonstrated by plotting the remaining intensity after each step against the corresponding temperature or alternating field

 iv.   Statistical analysis of palaeomagnetic directions. Each palaeomagnetic direction in a collection of samples is considered to have equal value and may be regarded as a unit vector. Each vector has a unit length but different direction.

  v.   Field tests of magnetization stability. Palaeomagnetic sampling may include a field test that can establish the stability of the magnetization over geological time. The field tests include fold test, conglomerate test, baked contact test and reversal test.

19) The small concentration of ferrimagnetic minerals in a rock gives it the ability to acquire a remanent magnetization. The untreated remanent of a rock is called its natural remanent magnetization (NRM). It may be made up of several components acquired in different ways and at different times. The remanence of a rock can be very stable against changes. A remanence

acquired at or close to the time of formation of a rock is called primary magnetizations; for example, thermo-remanent magnetization, and sedimentary remanent magnetization. A remanence acquired at a later time is called secondary magnetization. Examples of secondary magnetization are chemical remanent magnetization, isothermal remanent magnetization, and viscous remanent magnetization.