EXERCISE 7

Radioactive Dating and the Age of the Earth

For the last several hundred years, various researchers in the Western world have been interested in determining the age of the earth. In 1654, calculations based on Biblical Scripture led Archbishop James Ussher to conclude that the earth had been created in 4004 B.C. (i.e., about 6,000 years ago). Beginning in the eighteenth century, several attempts to calculate the age of the earth were made by scientists who measured certain properties and the rates of processes that occur on the earth. In one method, it was assumed that the oceans were originally fresh. By determining the rate at which salt is carried to the oceans by rivers and measuring the present salt content of the oceans, the age of the earth could be calculated. This calculation gave a figure of 99.4 million years. A second method was based on the assumption that the earth has been cool ing at a steady rate from an originally molten condition. By determining the rate of cooling and the earth's present temperature, the age of the earth could be determined. This calculation gave the earth an age of 20 to 40 million years. A third method involved measurements of the thickness of sedimentary rocks and the rate of deposition of sediment. This calculation determined that the earth was 450 million years old.

All of the above calculations based on measurements of the earth are erroneous because of incorrect assumptions about the earth. The oceans have probably always been as salty as they are now. The rate of cooling of the earth is disrupted by heating due to radioactive decay of elements in its interior. Finally, the rates of sedimentation may vary from several hours to thousands of years for a given thickness of sediment depending on the type of sediment and the environment of deposition. It wasn't until Antoine Becquerel's discovery of radioactivity in 1896 that a more reliable method for determining the earth's age could be developed.

In the process of radioactive decay, one element is transformed into another by the emission of particles from the nuclei of its atoms. These particles include alpha (α) rays, consisting of two protons and two neutrons, and beta (β) rays, consisting of single electrons. During radioactive decay, high energy electromagnetic waves called gamma (γ) rays are also emitted. It is important that the radioactive decay of a given element into another substance occurs at a known rate. This has led to an important concept known as <u>half-life</u>. A half-life of a radioactive substance is the time required for half of a given amount of the substance to be transformed into its decay (or daughter) product. For example, if we start out with 20 g of a radioactive substance with a half-life of a million years, after one million years, only 10 g will remain. The other 10 g will have been transformed into another element (the daughter). After another million years, only 5 g ($\frac{1}{2}$ of the remaining 10 g) of the radioactive substance will exist. After 3 million years, only $2\frac{1}{2}$ g of the radioactive substance will be left. This example illustrates that if the half-life and original amount of a radioactive substance in an object are known, the age of the object may be determined by measuring the remaining amount of the radioactive substance. In the example used above, how much time would have elapsed when only $1\frac{1}{4}$ g of the radioactive substance was left ? Answer: 4 million years, because

$$1\tfrac{1}{4} = 20 \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \quad \text{(4 half-lives of one million years have elapsed)}$$

Problems

7.1 Actinium 227 has a half-life of 13.5 years. If an object contains 120 mg of this radioactive substance, how much will be left after 54 years?

7.2 A fossil bone originally contained 128 mg of carbon 14. Carbon 14 undergoes radioactive decay to nitrogen 14 with a half-life of 5730 years. The bone now contains 16 mg of carbon 14. How old is the fossil bone?

The age of an igneous rock is a measure of the time it has existed since it solidified from a molten state. If a rock is remelted, its radioactive clock is "reset" - its age can only be determined to the point in time at which it experienced the remelting. Because of this fact, the oldest rocks on the earth may not represent the true age of the earth as they may have experienced melting some time after the formation of the earth. Geologists, therefore, use meteorites to determine the age of the earth (and the solar system) as this material is believed to represent the primitive material from which the planets formed. Radioactive dates can be determined by calculation or with the use of graphs such as the one below. Uranium 238 decays to lead 206, thus, the ratio of lead 206 to uranium 238 changes with time. By calculating this ratio in a rock, the corresponding age can be read directly from the graph.

7.3 Find the age of a meteorite if it contains 4.25 mg of lead 206 and 5 mg of uranium 238.

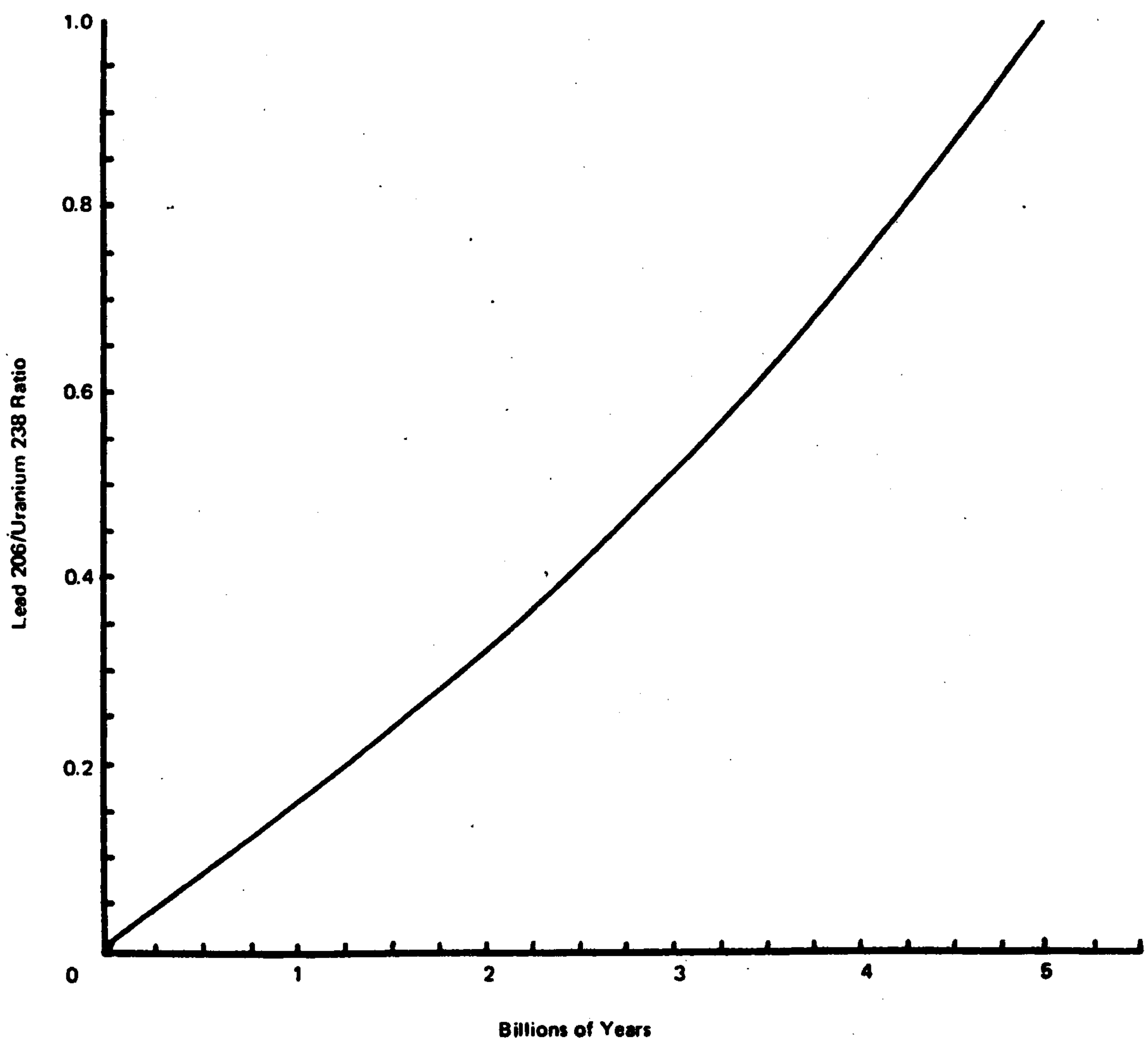

Figure 1. Graph showing variation $Lead^{206}/Uranium^{238}$ ratio with respect to time.