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EVIDENCE FAVORING THE RADIOACTIVE DISINTEGRATION OF SODIUM AS AN ELEMENT.*

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By the usual test for radioactivity, i.e., the continued ionization of a gas independent of other physical conditions, sodium as an element does not display any activity that is definitely greater than that found in all matter. And the ionizing activity of ordinary matter is so slight that it can not be stated with definiteness whether or not the matter is of itself radioactive. But radioactivity implies a more fundamental change than that of emitting matter and energy continuously. It implies an atomis disintegration. If α particles are emitted the atoms go by leaps and bounds to new atoms of other properties, while if β and γ radiations are emitted the wearing away of the atoms must be just as certain, though no one has been able to conjecture by what steps the changes may take place.

The fact that a given element does not give out a measurable ionizing radiation is not necessarily evidence that it is not radioactive. For example we may note the case of Radium C which gives no measurable radiations. Yet it disintegrates or decays to half value in 40 years. It is therefore known as a radioactive element.

If sodium is a radioactive element we may at present look for other evidence than direct radiations. We shall inquire if in past geologic time sodium has accumulated radioactively from other matter or on the other hand if sodium has disappeared or disintegrated into other forms of matter.

THE EVIDENCE FROM GEOLOGY.

The best evidence that we have for considering sodium a radioactive element is from geology. If the age of the earth is determined from radioactive data and the value accepted, we find that there is not accumulated in the ocean basin as much sodium as there should have accumulated during this time.

Different authorities give the age to range between seventy million and one hundred million years. On the other hand, the data of radioactivity gives the age to be about ten times as much as the figures noted above. The principles of the radioactive method are based on the determination of the amounts of helium or lead associated with known quantities of uranium in rocks of different epochs. The two principal assumptions that are involved are that during the age in question the amount of the uranium and its products which give rise to helium shall have remained constant and that the rate of production of helium shall have remained unchanged. Naturally these two assumptions can not be proved. It can only be said that there is no evidence that casts suspicion on these assumptions.

According to experiments by Rutherford and his colleagues, one gram of uranium in equilibrium with its products gives 10.7×10^{-8} cubic centimeters of helium per year. Now if we examine the rocks of the different geological

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epochs, we find the rare gas helium enclosed in the rock wherever uranium is found, and further the older the rocks the greater is the amount of helium associated with each gram of uranium. Obviously if we divide the total amount of helium per gram of uranium by the above constant, 10.7×10^{-8}, we obtain the number of years during which the uranium has been depositing helium, i.e., the age of the rock containing the uranium.

The greatest chance for error in the above methods of calculation lies in the possible escape of helium from the rock containing the uranium. Therefore the age of the rock as calculated might be too small. The method would therefore set a minimum limit on the age of the earth.

But if we accept Boltwood's conclusion, that the lead associated with uranium in rocks resulted from the radioactive disintegration of the uranium series of elements, and that one gram of uranium gives rise to 1.88×10^{-11} gram of lead per year, we have a check upon the results obtained with the helium deposit. In general the lead deposits give a somewhat larger age for a given rock than do the helium deposits, which is what we should expect if the helium may escape.

Using the method outlined above, Rutherford in 1906, found the age of a sample of fergusonite to be 240,000,000 years. This was deduced as outlined from the fact that 1.81cc. of helium was taken from one gram of the mineral which contained about 7% uranium.

Strutt by the same method found two stones from Quebec of the Archaean age to be 222 and 715 million years old, and two of the same kind from Norway to be 213 and 449 million years. He also found the average minimum value for Haematite of the Eocene period to be 31 million, the same from the carboniferous period limestone to be 150 million years, while for the Archaean age the average was 710 million years.

Holmes using as a basis the ratio of the lead to the uranium in the rocks found the values given in the following table:

Period.		Age.
Carboniferous		340,000,000 years
Deconian		370,000,000 years
Pre-carboniferous		410,000,000 years
Siluvian		430,000.000 years
Pre-Cambrian	Sweden	1,025,000,000 years
	U. S.	1,310,000,000 years
	Ceylon	1,640,000,000 years

The above results show that the age of the earth in its present form must be many times a million years old.

However, if we take the evidence as based on the result that is obtained by dividing the total amount of sodium in the ocean by the annual output of all the rivers of the globe, we find that the age of the ocean can not be more than one hundred million years old. Two of the most eminent geologists, F. W. Clarke and J. Joly, think that 70,000,000 years is much more nearly the correct age based upon the solvent denudation of sodium.

There is therefore a discrepancy between the age of the earth as deduced by the two methods. Joly, in the Philosophical Magazine for September, 1911, favors the view that the radioactive constants are probably in error, because they have not been taken over data extending over a sufficiently long time, and under proper circumstances free from doubtful assumptions.

I wish to suggest that there is another explanation of the discrepancy that requires no distrust of the radioactive constants as they have been experimentally determined. In fact the explanation is merely an extension of our knowledge of radioactivity to a wider field. The discrepancy disappears if sodium is supposed to be a radioactive element. If we accept the present data of radioactivity as authorative, then it must be admitted that there is not enough sodium in the ocean. Perhaps during geologic time elements of higher atomic weight may have been disintegrating into sodium, and therefore the annual output of the rivers now is not the average output for all time in the past. That is, the sodium over the land has been increasing by radioactivity production while sodium in the ocean has been increasing almost entirely by the annual river supply. Obviously this would give a greater age for the ocean. Or perhaps the average amount of sodium discharged annually to the ocean has not changed markedly, but that the sodium in the ocean has been very slowly disintegrating into other elements. It seems that our present information is not sufficient to decide which of these two views is most plausible. Either condition is in agreement with an earth of older age. Both conditions may have prevailed, and both ideas are directly in line with recent progress in science. Either is in agreement with further facts as presented by geochemistry.

FURTHER EVIDENCE IN GEOLOGY INDICATING THE DECAY OF SODIUM.

There are other soluble elements than sodium carried to the ocean by rivers, which indicate quite a different age of the earth, and consequently favor the radioactivity of sodium. Only those elements that are not deposited in the ocean bed or otherwise removed from the ocean water may be considered as for reliable information. Clark, in his Geo-Chemistry, second edition, p. 125, gives the following facts; the last column are my own deductions, however:

	Annual output from rivers, metric tons$\times10^3$	Amount in the ocean, metric tons$\times10^{12}$	Age of ocean
Chlorine......	155,350	25,538	160×10^6
Sodium.......	158,357	14,138	89×10^6

The geologists do not believe that the rivers carried on the average any less sodium previously than they do now. But if they did, they should also have carried less chlorine. We may therefore for checking purposes say nothing concerning the annual river output further than that it should have varied alike with sodium and chlorine. On this assumption the above figures show that there is not as much sodium in the ocean as there should be. Disregarding the radioactivity data altogether we see that the above evidence favors the radioactive decay of sodium as an element. Clarke goes further to state, "We can understand the accumulation of sodium in the ocean and some of the losses are accounted for, but the great excess of chlorine in sea water is not easily explained. In average river water sodium is largely in excess of chlorine; in the ocean the opposite is true, and we can not help asking whence the halogen element was derived. Here we enter the field of speculation and the evidence upon which we can base an opinion is scanty indeed."

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My comment on Clarke's statement would at once give an explanation of the excess of chlorine over sodium in sea water. It is, that if the chlorine has accumulated and disintegrated in the ocean it has been at a much slower rate than has been the disintegration of sodium in the ocean or slower than the decay of the parent of sodium where it was derived from the land.

It is obvious that whether we consider the radioactive data or only the data of geo-chemistry, that it is convenient to assume sodium to be a radioactive element. There has been proposed by no one any other explanation for the discrepancies to which attention is called in this paper. However, it may be noted that the age of the earth as calculated from the chlorine in the ocean is yet much smaller than that given by the radioactive data. I do not believe this discrepancy detracts from the argument as presented.