Carbon dioxide gas in the Earth's atmosphere

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On the basis of forecasts of extraction of fossil fuels during the next fifty years an analysis is made of the accumulation in the Earth's atmosphere of carbon dioxide released in industrial processes. The effect of such changes on the Earth's climate and on harvests is discussed.

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The most intensive aspect of the productive activity of man involves the processing and burning of fossil fuels—oil, coal, gas, and organic wastes. More than 95% of current energy production is provided by this means. An incidental result of this activity is the emission into the atmosphere of carbon dioxide gas[1]; this action of man on the Earth's atmosphere significantly exceeds all others in scale. It is therefore easy in the present case to investigate the changes in the environment which will result from the productive activity of man. The present article is devoted to an analysis of the problem of accumulation of carbon dioxide gas in the Earth's atmosphere and the consequences to which this may lead.

It is necessary first of all for us to understand what fraction of carbon dioxide gas released in industrial processes remains in the Earth's atmosphere and what fraction goes into other circulation pathways. Here we shall depend on the measurements of the Mauna Loa observatory in the Hawaiian Islands. According to these measurements, from 1958 to 1978 the average content of carbon dioxide gas in the atmosphere increased approximately from 313 ppm[1)] to 328 ppm. It is natural to associate this change with the productive activity of man. If the increase in the amount of carbon dioxide gas in the atmosphere during this time is compared with the quantity of carbon dioxide gas produced as the result of burning fossil fuel, we find that approximately 40% of the industrial carbon dioxide gas remains in the atmosphere, and the remainder goes into other circulating pathways. This proportion is observed also in shorter time intervals, but with poorer accuracy. This ratio permits construction of a simple model of the balance of carbon between the atmosphere and other circulation pathways[2)] which is presented in the figure.[2-5] This provides the possibility of predicting the accumulation of carbon dioxide gas in the atmosphere in the next few decades. In making this prediction we shall utilize the data given by Rotty[1] and Bolin,[3] according to whom in the year 2025 26 billion tons of carbon in the form of carbon dioxide gas will be emitted into the Earth's atmosphere, which corresponds to an annual increase of 3.4%.

We note that in this case the scale of several decades is the most favorable for prediction. On the one hand, this permits us to neglect the short-term variations on the scale of a year which are associated with the weather. On the other hand, during this time the change in the plant covering of the Earth, due partly to the agricultural activities of man, and other global changes of the same kind will have little effect; naturally it is assumed that the change in the content of carbon in the atmosphere and the other circulation pathways during these times is relatively small, so that the processes which determine the nature of its exchange are preserved.

In constructing a model of the balance of carbon between the atmosphere and the other circulation pathways we shall make use of the following considerations. As the amount of carbon dioxide gas in the atmosphere increases, the flow of carbon dioxide gas from it into the other circulation pathways as the result of photo-

[1)]ppm is the number of parts per million. 313 ppm means that in a million molecules of air there are 313 molecules of carbon dioxide gas.

[2)]The distribution of carbon in the various circulation pathways is as follows.[2] The atmosphere contains about 700 billion (700×10^9) tons (metric tons) of carbon in the form of carbon dioxide gas; the biosphere contains 800 billion tons of carbon; the organic matter in the soil contains 1000–3000 billion tons of carbon; the ocean contains approximately 40 000 billion tons, of which about 600 billion tons is in the upper layers (depths up to 100 meters). Only a part of this carbon, that contained in the biosphere and in the upper layers of the ocean, effectively takes part in exchange with the carbon of the atmosphere.

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synthesis and assimilation into the upper layers of the ocean increases in proportion to its content in the atmosphere. On the other hand, the reverse flow of carbon dioxide gas into the atmosphere as the result of decomposition of organic matter, respiration of plants, and oxidation changes in proportion to the amount of carbon in the corresponding circulation pathways of carbon. In this way in the process of accumulation of carbon dioxide in the atmosphere the relation between the amount of carbon in the atmosphere and the other pathways with which the atmosphere exchanges carbon is retained. This forms the basis of the model of the balance of carbon (see Fig. 1), where the flows of carbon are taken in accordance with Refs. 2 and 6. Data on the accumulation of carbon dioxide in the atmosphere are given in Table I.[3)]

Let us now analyze the consequences of an increase in the carbon dioxide content in the atmosphere and their effect on the conditions of life of man. The greatest value of atmospheric carbon dioxide is due to its participation in biological processes. Without carbon dioxide in the atmosphere, photosynthesis—the most intensive biological process—would be impossible. At the present time the rate of utilization of solar energy in photosynthesis is almost an order of magnitude greater than the total power of the world's power plants. Under optimum conditions for photosynthesis—adequate moisture and mineral fertilizers, etc.—the rate of photosynthesis varies in proportion to the concentration of carbon dioxide in the atmosphere as long as this quantity does not reach the percent range.[7] Therefore an increase in the amount of carbon dioxide in the atmosphere will make possible an increase in harvests. For this reason the accumulation of carbon dioxide in the atmosphere is favorable for man. On the existing scales, the effect of a change in the carbon dioxide content in the atmosphere on the health of man is unimportant. The air which man exhales contains several percent carbon dioxide, and at this level changes are considered unimportant.

Another manifestation of the accumulation of carbon dioxide in the atmosphere involves the greenhouse effect. This is widely discussed in the literature. If we assume that the Earth's atmosphere is absolutely transparent in the infrared region of absorption of carbon dioxide molecules, then according to a number of calculations[8-17] a doubling of the amount of carbon dioxide in the atmosphere will lead to an increase in the temperature of the Earth's surface by 1.5–3°. The difference between the various calculated values is explained by the different means of approximation of the carbon dioxide spectrum, different temperature distributions with height in the atmosphere, and different means of separating the additional radiation flux incident on the Earth's surface into the various channels of the Earth's heat balance. The change in the temperature of the Earth's surface relative to the 1958 value as the result of the corresponding increase of carbon dioxide in the atmosphere is given in Table I. These data are based on the calculations of Ref. 18. As can be seen, the presence of water vapor in the atmosphere substantially reduces the effect of carbon dioxide on the Earth's heat balance. The numbers given for average atmospheric humidity (70%) are obviously further reduced if the limited transparency of the atmosphere in the region of absorption of carbon dioxide molecules due to absorption by other molecules, aerosols, and atmospheric dust particles is taken into account. Nevertheless, fifty years from now the effect of anthropogenic carbon dioxide on the Earth's climate may become appreciable.

Although the accumulation of carbon dioxide in the atmosphere is the most striking result of the influence of man on the Earth's atmosphere, from the point of view of heat balance and the Earth's climate this is not the greatest action of man on the atmosphere. The fact is that a change of the optical properties of the atmosphere in the infrared region capable of producing an increase in the Earth's temperature by a degree is possible on introduction into the atmosphere of impurities of optically active molecules with a concentration 0.01–0.1 ppm. The concentration of the principal impurity particles in photochemical smog is in this range, i.e., with this concentration of impurity particles in the atmosphere its chemical composition may turn out to be unacceptable for man. For this reason a no less important role than that of carbon dioxide for the Earth's climate and the physical and chemical properties of the atmosphere in the future may be played by ozone and compounds of nitrogen, sulfur, and halogens which are produced in the atmosphere by man's ac-

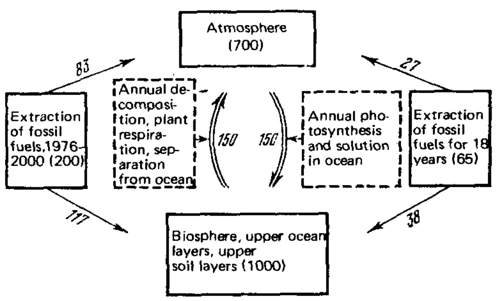

FIG. 1.

TABLE I. Carbon dioxide gas in the Earth's atmosphere.

Year	1958	1978	2000	2025
Amount of carbon in fossil fuel burned since 1958, billions of tons	—	75	260	680
Increase in amount of CO_2 in the atmosphere since 1958, %	—	5	16	42
Carbon dioxide concentration in atmosphere, ppm	313	328	363	444
Increase of Earth's surface temperature, degrees:				
for $\eta=0$ *)	—	0.08	0.29	0.74
for $\eta=70\%$	—	0.05	0.17	0.46

*) η is the atmospheric humidity.

[3)]In mining and burning fossil fuels, man substantially changes the geological times corresponding to the exchange between the carbon occurring in the interior of the Earth and on its surface. With the existing scale of mining of useful deposits this time is reduced from 3 billion years to 5 million years.

tivities. Since the processes which occur with involvement of these materials are due to small concentrations of these particles, it may turn out that the changes due to these processes in the atmosphere will not be manifest until they reach a dangerous level. This requires an extremely detailed investigation of the physical and chemical processes occurring in the atmosphere and of man's influence on them.

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