Global problems and energy[1)]

P. L. Kapitza

Institute for Physical Problems, Academy of Sciences of the USSR
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During the present century due to an increase in the number of people on the earth's globe and with a growth of material culture technological and energetic processes have begun to take place which have started to alter the nature of the whole globe. Some of these changes have become so significant as to constitute a danger for the safe existence of humanity as a whole. In this paper it is shown that global problems usually develop according to exponential laws when an acceleration of the processes acquires the character of an explosion. The solution of global problems consists of bringing them under control and preventing an explosion. One of the problems is associated with the depletion of energy resources which are a basic factor determining the level of contemporary civilization. It is shown that the only way to escape the crisis consists of making a transition to atomic energy. An examination is made of the technical, scientific and social diffuclties which lie in the path to this solution and which it is necessary to resolve.

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Global problems are problems which must be solved on a global scale. Already in ancient times such problems were described in artistic and religious books; they were, for example, The Last Judgement, The Universal Flood.

Now global problems have become real, and the necessity to solve them is the gravest social and scientific task for humanity as a whole. Scientists must find these solutions and provide the proper foundations for them, while statesman must realize them on an international scale. Therefore at present the study of such problems becomes more and more a central activity both of scientists and of statesmen.

The reason that such global problems arise is well known: man differs from animals principally by the fact that an animal adapts itself to nature, while man transforms it and adjusts it to his requirements. In our century, owing to the increase in the number of people on the earth's globe and with the growth of material culture, technical and energetic processes have begun to take place which have started to alter the nature of the whole globe. It is now becoming evident that some of these changes are sufficiently significant that they represent a danger for the safe existence of humanity as a whole.

This was first realized by mankind when nuclear war became possible. It is now generally accepted that in the event of nuclear war breaking out the already existing supply of atomic bombs is sufficient not only to destroy a significant part of the population of the globe but in principle to poison the globe with radioactivity to an extent that the remaining part of the population will either perish or will be forced to exist at a level similar to that of prehistoric man.

As long as people directing the affairs of state are conscious of this and are ruled by reason and not by emotion the possibility of nuclear war breaking out will remain under control.

Before proceeding to the analysis of some specific global problems I think that it is useful to point out a characteristic common to them all to which usually insufficient attention is paid.

This common characteristic consists of the fact that phenomena associated with global problems usually develop according to a law determined by the so-called geometric progression, or, in other words, exponentially. With respect to the growth of population this was first noted already two centuries ago.

The law of geometric growth contains within it a rather unexpected property—it invariably leads to a phenomenon which it is customary to describe as an explosion.

This was noted already in ancient times. In one oriental tale it is related that some wise man had rendered to a certain king a considerable service. Wishing to show his gratitude to the wise man the king offered him to choose his own reward. The wise man asked to be rewarded by grain. He asked that a single grain should be placed on the first square of a chess board, double the amount—two grains—to be placed on the second square, four grains to be placed on the third square, etc. following a geometric progression to the 64-th square. The tale relates that the king was surprised by the modesty of the wise man, but when the payment of the reward began it turned out that it exceeded the wealth of the kingdom. This problem is often posed in the upper grades of our schools, and calculations show that the total weight of the grains will exceed one hundred billion tons; this is more than ten times larger than the annual grain harvest of the whole world!

But processes developing according to a geometric

[1)]Lecture delivered at Stockholm University on 5 May 1976

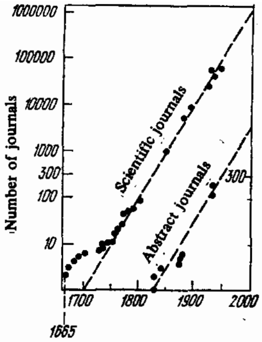

FIG. 1. The growth in the number of scientific journals beginning with 1665.

progression have yet another property. It is not difficult to show that not only the amount but also the rate of increase of the amount follows a geometric progression. This leads to the fact that after a sufficient lapse of time this rate can also become arbitrarily large. It is customary to describe a rapidly developing process as an explosion.

This explains why at present we speak of a demographic explosion, although the increase in the population on the earth's globe in the present century remains on the average approximately 2% per annum. It is of interest that we also speak of a scientific–technological revolution, as if an unusually vigorous growth of science has at present begun suddenly. In actual fact this is not the case and this can be shown in the following manner.

In Fig. 1 years are plotted along the horizontal axis, and along the vertical axis on a logarithmic scale is plotted the number of scientific journals published everywhere.[1] It can be seen that during the last 300 years, i.e., since the time when due to the invention of printing of books and to the appearance of postal communication science began to be developed on an international scale, the number of journals has increased according to a geometric progression and their number has invariably doubled every 14 years. Of course, it is natural to consider that the number of published scientific papers is proportional to the activity of scientists; then the growth in the number of journals characterizes the growth of science.

As can be seen from this diagram the law of exponential growth has not been violated until now and mathematically there is no reason to speak of any kind of an explosion. Evidently a process developing in accordance with the geometric progression must reach a limit and stop. The approach to this limit will be in the nature of an explosion.

I will mention another example quite familiar to us of a phenomenon developing according to a geometric progression until it reaches a definite limit,—it consists of infectious diseases. An infection enters a human organism; suppose that this is a bacterium which reproduces by undergoing division every hour. The number of bacteria in the human organism begins to grow just as the number of grains on the squares of a chess board. It is not difficult to calculate that in three days the number of bacteria would reach the astronomical number of 10^{21}, and this is impossible since the weight of bacteria would exceed the weight of the man. Of course, the process must cease before then, and it is well known how this occurs in the course of the disease. When the concentration of bacteria attains a certain value a man feels ill and this occurs suddenly like an explosion. Further the process can cease in three different ways: either the increase in the number of bacteria in the man's organism ceases and the man regains his health, or the bacteria continue to multiply and the man succumbs together with the bacteria. Finally, there exists another special solution—this is equilibrium when the man's organism destroys as many bacteria as are produced. Then the illness becomes chronic.

An infectious disease which develops according to a geometric progression is in many respects analogous to those global processes which have begun to occur on the earth's globe. We have suddenly felt ill and in order not to perish it's time to think about a method of treatment. But for this, of course, it is necessary to understand the nature of our illness. Of course, one of the main global problems is the incessant exponential growth of the population of the earth which is particularly rapid in some countries. This growth must sooner or later cease if for no other reason than because there will not be sufficient food to sustain the life of the people.

The problem which confronts mankind consists of determining how this growth can be stopped painlessly, i.e., not by means of death from starvation as is beginning to occur now.

It is well known that this problem is now being widely discussed, but so far no generally accepted means for solving it have been found. We shall not touch upon this problem, but shall restrict ourselves by assuming that within the next hundred years the number of people on earth in one way or another will not noticeably vary. We shall concentrate on the problem of how one can guarantee to people a sufficiently high and constant level of civilized life and we shall show that this is attainable only if the energy problem will be solved on a global scale.

The connection between the level of civilized life and the energy supply for mankind is well known. It is clearly illustrated in Fig. 2 where along the horizontal axis we have plotted the gross national product for a number of countries calculated per annum per person and expressed in dollars, and along the vertical axis we have plotted the energy utilization per person expressed in terms of coal (in kilograms per annum).[2] As can be seen from the diagram, within limits of natural fluctuations there exists a simple proportionality between the gross national product per person and the energy resources of a country. This, of course, is quite understandable: in order to manufacture any item it is necessary to perform work and, consequently, to expend energy. Statistics show that in the most developed countries on the average 10 kilowatts are available per person. This is several hundred times more than the energy produced by the muscular work of a person. Thus, the growth in the material well-being of man is most closely connected with the energy produced. At present the utilization of energy is rapidly growing, and

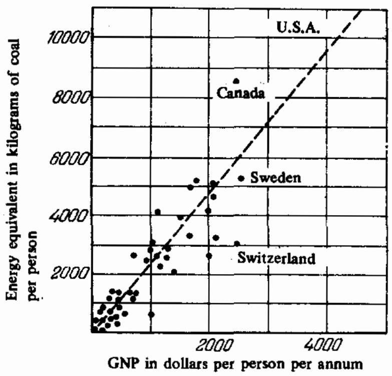

FIG. 2. Utilization of energy and the cross national product (GNP) per person. Data refer to 1968, and are compiled according to the materials of the United Nations and the International Bank for Reconstruction and Development.

not only because the material level of life of people in developed countries is rising, but, principally, because of the necessity to raise the level of life in developing countries. Moreover, an increase in the utilization of energy is associated with the necessity of solving a number of global problems that are arising.

As is well known, at present there is beginning to take place a depletion of reserves of mineral raw materials required for industry, primarily of metals such as silver, tin, copper, and a number of others. This leads to the necessity of extracting them from ores of lower content. Already it turns out to be necessary to extract certain metals (for example, magnesium) dissolved in sea water. This requires large expenditures of energy per unit weight.

The use of energy will also increase in our efforts to combat pollution of the environment which already occurs on a global scale and begins to acquire menacing dimensions. It is well known that technological processes which do not give rise to noxious wastes in manufacturing processes such as, for example, production of paper, lead to an increase in the utilization of energy.

Further increase in the efficiency of agriculture requires the production of mineral fertilizers, in particular, the fixation of nitrogen from the air, and this also leads to an increase in the expenditure of energy.

Finally, one can assume that in future as a result of the development of chemical technology and the appearance of the possibility of the production from inorganic materials of organic ones, including protein, a possibility will arise to assure the feeding of people by synthetic products making it ever less dependent on products which at present are derived from agriculture. This will also require expenditure of energy.

This role of energy in the development of the material culture of mankind explains why at present the world utilization of energy increases according to a geometric progression and during the last 15 years the growth amounts to 5% per annum. This is the highest index of growth in the world economy, and everywhere the capital expenditures for energy production are the dominant ones.

In view of this dominant role of energy production in world economy the overcoming of the currently imminent energy crisis represents for mankind the greatest global problem.

The cause of the approaching crisis is evident and well understood. Not less than 90% of the sources of energy which are being utilized at present are different types of fuel such as coal, oil, gas, etc. The chemical energy contained in them has been accumulated as a result of biological processes in the course of thousands of years. It turns out that at the present rate of their utilization their reserves on the earth's globe will be used up in the near future. Of course, it is impossible to determine exactly when this will occur, but one can with great certainty assume that this will occur in the course of one–two centuries. Of course, this time can be extended by a more economic use of energy, by means of improvement of technology and by means of stopping the expenditure of energy on armaments, etc. This will only postpone the crisis, but it can not be prevented, since, according to the law of conservation of energy, we can not realize a *perpetuum mobile* with the aid of which we might produce energy. Therefore, if other sources of obtaining energy are not found to replace the fossil fuel being utilized at present an inevitable decrease in the utilization of energy will occur, and consequently this will lead to a decrease in the material well-being of people.

The way towards the solution of this problem is quite evident,—it is necessary to find sources of energy which would be practically inexhaustible with time. The principal ones among them are well known—this is radiation from the sun, geothermal heat, hydro energy of rivers and of tides. But as analysis has shown[3] they can not solve the problem on the required scale in a sufficiently economic manner.

The principal difficulty arises because the greatest part of the energy utilized at present in world economy goes to heavy industry (metallurgy, production of machinery, transport, building, etc.) In order to satisfy these requirements cheap energy is needed in amounts of hundreds of millions of kilowatts. This is many times greater than the energy which we call "consumer" energy and which we utilize for refrigerators, washing machines, television sets, etc. If we would want to satisfy the energy requirements of the whole world economy by utilizing the energy of solar radiation, then in order to obtain a power output of only one million kilowatts it is necessary to absorb it from an area of 10 square kilometers.

Calculations show that in the case of all the proposed methods of transforming radiation into mechanical or electrical energy the capital expenditures are not justified by the energy obtained. This is due to the fact that for effective utilization of energy its flux density must be sufficiently great. Solar energy does not have such a flux density.

Calculations show that geothermal heat due to the poor thermal conductivity of the earth's outer shell also does not have a sufficient energy flux density in order to be profitably exploited. Only in regions where volcanoes are situated does the geothermal heat have a sufficient energy flux density to be profitably utilized. But there are few such regions. For example, in Italy geothermal heat has been successfully utilized for many years, but it amounts to only 2% of the energy balance of the country.

The situation is somewhat better with utilization of hydro energy. Practice shows that electrical energy can be profitably generated only in the case of high heads in mountain regions. This restricts the scale of utilization of hydro energy. In a world energy balance hydro energy at present amounts to not more than 5%, and, apparently, this is its limit.

The situation is still worse with utilization of wind. Its energy flux density is not only small but is extremely inconstant.

Nevertheless, life shows that utilization of solar energy and of the energy of wind and water can be useful for people for the solution of energy problems on the scale of consumer requirements, where one can afford to pay considerably more for energy. As regards the solution of the principal problem of energy requirements at high power these sources can not aid in overcoming the approaching energy crisis.

If this energy crisis were to have arisen 40 years ago, prior to the discovery of nuclear energy, humanity, doubtlessly, would have been confronted by a catastrophe and human culture would have approached a dead end.

But at the present time one can with complete confidence assert that the sources of nuclear energy provide a scientifically based possibility of solving the approaching energy crisis.

But even along this path there are its own characteristic difficulties which people still have to overcome.

As is well known, at present there exist two real methods of obtaining energy at high power in nuclear processes. The first of these—is the evolution of energy in the fission of nuclei of heavy elements, such as uranium, which occurs as a result of neutron bombardment. This process has the nature of a chain reaction and is self-sustaining. It has been well studied, and on its basis an atomic bomb has been realized of the type which was released on Hiroshima and Nagasaki. In energy producing reactors this reaction has been slowed down, has become stable, and the energy obtained is being successfully utilized for profitable production of heat and electrical energy on the scale of millions of kilowatts. The reserves of uranium in nature, if they are utilized economically in reactors of a particular type, the so-called "breeders," may be sufficient for thousands of years. Moreover, some scientists assert that extraction of uranium dissolved in sea water in practically unlimited quantities can become profitable even now.

The following generally recognized difficulties[3] lie in the path of transition of the whole energy supply problem to nuclear fuel and they must be overcome.

The principal one of these problems consists of the fact that in the course of utilization of uranium as a nuclear fuel in reactors there occurs an accumulation of a large quantity of radioactive substances, and if an accident should occur and the contents of a reactor should escape into the environment, then poisoning of live organisms and, of course, principally of people will occur. The horrors of poisoning by radioactive substances of people are well known as a result of the consequences of atomic bombs dropped by Americans on Hiroshima and Nagasaki. It turned out that due to radioactive poisoning a fraction of the people perishes over a short period of time. But another part of the population perishes over a period of several years, usually from leukemia or other forms of cancer diseases.

The escape outwards of the radioactive content of a reactor can occur if cooling water ceases to be supplied to the reactor. Then the elements of the reactor overheat, the shielding surrounding it is destroyed and the contents escape outwards. In the language of the specialists this is known as "core meltdown." In order that this should not occur a number of preventive devices is used. The reliability of these safety measures is estimated numerically: the probability of an accident occurring is calculated. The probability of an accident at atomic power stations that have been constructed in the U. S. A. until now has been estimated by the constructors of the reactors as being in parts per billion and accidents were assumed to be simply impossible. However, many people have regarded these calculations as being unrealistic.

The reliability of this kind of estimates was radically shaken by an accident which occurred at the Browns Ferry electric power station in California in March 1975. Approximately a year later there was published an official conclusion of the commission[4] appointed to establish the cause of this accident. I shall quote from the conclusions only certain characteristic features of this occurrence. The accident occurred as the result of a fire which took place underneath the area where the control center of the electric power station is situated. The cables were set on fire. The cause of the fire was an ordinary candle with the aid of which a worker was trying to discover the leak from a pipe which supplied compressed air.

Only 15 minutes after the conflagration when people were convinced that the available firefighting means were insufficient did they start to call out the fire brigade. Then it turned out that its telephone number was incorrectly recorded. Only an hour after the conflagration did the fire brigade arrive, and then it turned out that there were no instructions as to how one should fight fight fires in a nuclear electric power station. Therefore in the course of the next 6 hours people did not know what to do, and then started to put the fire out using water which turned out to be quite successful. The commission established that, since the emergency water supply was disrupted, if the fire had not been put out then after a short period of time the elements in the reactor would no longer have been cooled by water and a catastrophe would have occurred similar to the one of which I spoke above. It should be noted that the Browns Ferry atomic power station is situated in a densely populated area. Since the measures provided for the evacuation of population were not put into operation, then in terms of the number of perished and poisoned people the potential catastrophe would have been comparable with the Hiroshima catastrophe.

Of course, this accident has shown that mathematical methods of calculating probabilities of this type of occurrence are inapplicable, since, as has happened in the present case, probabilities are not taken into account of what happens as a result of human error: of a workman with a candle, of a telephone number incorrectly recorded by someone, of the fact that no one had provided instructions for fire-fighting in atomic power stations, etc.

Now, when all the details of this accident have become known, the problem has arisen of the future fate of atomic energy production in the U. S. A.

Of all the atomic electric power stations in the U. S. A., 35% are situated in California. Therefore the population of that state (20 million persons) is much worried by the fact that the greater number of these stations are constructed in a manner similar to the Browns Ferry station and, moreover, it is proposed to build a number of analogous stations. Half a million persons have signed a petition in which they demanded that the government of the state should not only cease the construction of such stations but should also shut down the atomic stations already existing in California. According to the laws of the state a referendum had to be held on this problem, and in order to obtain permission for subsequent construction of atomic stations a two-thirds majority is required.[5] The referendum took place during the summer of 1976 and approximately 70% of those polled voted for the development of atomic energy, but subject to a tightening up of the measures guaranteeing the reliability of exploitation of atomic power stations.[2)]

In the U. S. A. at present there are already 59 nuclear reactors in operation, and they produce 4% of all utilized electrical energy. A further widespread development of nuclear energy production is planned, and therefore the Senate reacted very seriously to the accident at Browns Ferry and the question of the reliability of nuclear electric power stations was investigated in a special committee on atomic energy. At present extensive testimony to this committee has been published[6] of three leading constructors according to whose plans the majority of nuclear reactors has been built, including the one at Browns Ferry. The testimony provides data on a large number of accidents and a completely unsatisfactory guarantee of the safe exploitation of reactors is brought out. They consider that under the conditions existing in the U. S. A. at present for the development of nuclear energy production a catastrophe on the scale of Hiroshima will occur sooner or later. This is further confirmed by the fact that at present in the U. S. A. not a single insurance company undertakes to insure nuclear electric power stations. These leading constructors of reactors have now left the employ of the General Electric Company motivating this by the fact that morally they do not feel able to take the responsibility for the safe operation of existing electric power stations, and for the consequences of disasters to which possible accidents might lead.

But, of course, under present conditions the global problems of the production of energy at high power will not be able to be solved without nuclear energy, and doubtlessly, a way out of the situation that has been created will be found. It will have to be based on the premise that in case of any accident that might occur in a reactor at an atomic electric power station it must under no circumstances acquire the character of the Hiroshima catastrophe. Solutions are already being proposed now, and they consist, for example, of placing the nuclear reactors of electric power stations at a sufficient depth underground as is being done now in the case of underground tests of atomic explosions. Apparently, although this will make the construction of electric power stations more expensive it can make them completely safe.

Another possible solution is to place the atomic power stations in regions where there is no population, for example, on uninhabited islands, and to convert the energy generated by them into chemical energy: for example to decompose water and to utilize hydrogen in liquid form as fuel. This fuel will be much better than oil since on burning it will not pollute the air.

Before solving the problem of the widespread development of atomic energy it should be noted that atomic energy utilizing uranium fuel requires the solution of several other problems.

The most difficult of them is the storage of radioactive wastes. The difficulty consists of the fact that their radioactivity is quite great and, moreover, decays only very slowly. Therefore any containers in which they might be stored can with time be destroyed under the action of radiation, and the radioactivity could then spread. Calculations show that in going over to nuclear power production as the principal method of power production the resulting amount of radioactive wastes becomes so great that their safe storage becomes a problem which is difficult to solve, and until now there exists no definitive and generally accepted solution.

Finally, in capitalistic countries there exists yet another problem, not of a technical but of an internationally political character which also requires solution. It is well known that for a more complete utilization of uranium reactors based on fast neutrons are used, they are called "breeders." In them uranium is almost complete-

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[2)] In order to make possible the further development of atomic energy in the State of California the State Assembly has adopted, just prior to the referendum of June 3, 1976, a number of laws which establish strict control to guarantee the safety of atomic electric power stations (both planning and exploitation) including their possible construction underground. Also by legal means the necessity has been established to guarantee safety in handling nuclear fuel and its wastes. These measures influenced the outcome of the referendum which was carried out on June 8, 1976.

ly transformed into plutonium which is the best atomic "fuel." In the course of time this will lead to the situation that plutonium will become very widespread and accessible. But plutonium is the basic element from which an atomic bomb is made. In order to make a bomb it is necessary to have only a few kilograms of plutonium and, moreover, at present the construction of an atomic bomb is no longer a secret. Under these conditions the possibility is not excluded that an enterprising group of gangsters can without much effort utilize an atomic bomb for blackmail.

Doubtless people confronted with the approaching energy crisis will find a solution and will be able to overcome the difficulties enumerated above associated with the utilization of nuclear energy generated by the fission of uranium. But it is now already becoming clear that the solution of this problem will have to be effectively realized on an international scale.

I shall also mention, but only briefly, other methods of utilizing nuclear energy since so far they have not yet been realized in practice.

First of all this is the method of obtaining energy not by means of fission of a heavy atom such as uranium, but conversely by the process of fusion of light atoms which, as is well known, can occur with an energy yield.

This is the so-called thermonuclear process. At present it is realized in the hydrogen bomb in which helium and neutrons are produced as a result of fusion of isotopes of hydrogen. This process is accompanied by a large yield of energy and occurs only at a very high temperature of hundreds of millions of degrees. At this temperature all substances are in a gaseous state in the form of plasma when electrons in atoms are completely removed from their nuclei.

It turns out that it is quite possible to produce such a plasma for a short period of time during which an explosion of an atomic bomb takes place. This process occurs in the so-called hydrogen bomb which at present is hundreds of times more powerful than a uranium or a plutonium bomb.

In order to utilize the thermonuclear reaction for obtaining energy one must find a method of carrying it on continuously and, by comparison with the hydrogen bomb, on a small scale. This has turned out in practice to be a problem which is very difficult to realize and which to date has not yet been solved technically.[7]

Scientists and engineers all over the world are at present diligently working on this problem. Although the problem has not yet been solved, nevertheless until now there have not been discovered any scientific or technical obstacles which are in principle insuperable lying on the path to its solution, and I personally think that with time controlled thermonuclear fusion will be realized.

It is very important to find the solution, since the energy obtained by this method is not associated with the difficulties arising in the use of uranium fuel which I have mentioned. In the case of a thermonuclear reaction the amount of accumulated radioactivity is so small that its presence does not create danger. The thermonuclear process can not be utilized for the production of atomic bombs.

And, finally, the fuel which is utilized in thermonuclear reactors is the hydrogen isotope-deuterium and amounts of it stored in the ocean are quite sufficient to supply mankind with energy for many thousands of years. During that time, of course, still other methods of solving the energy problem will be found.

Finally, there exists still another method of obtaining energy on a large scale. In practice it is apparently not realizable, but scientifically it is well founded. On the basis of our present concepts of cosmogony it is considered that when our universe was being created another one could have been created of a similar size but consisting of antimatter. The existence of antimatter has been demonstrated experimentally, it is obtained in accelerators, but only in amounts of a few nuclei. One of the properties of antimatter consists of the fact that on coming into contact with matter they are both annihilated and are converted into energy. It is not difficult to calculate that one gram in such a reaction yields an amount of energy equivalent to that obtained by burning 10,000 tons of coal. Thus, one ton of antimatter would be quite sufficient to supply the whole earth with energy for a year.

But how would we obtain this antimatter from the antiworld? It has been supposed that a small amount of antimatter could penetrate in the form of meterorites into our cosmic space since it is highly rarified. Their collisions with atoms would be so rare that on penetrating into our cosmic space they would not be totally annihilated. By capturing with the aid of satellites this material from the cosmic space and bringing it to earth we could have the most perfect source of energy. It is known that attempts to find antimatter in cosmic space so far have not met with success.

But even if antimatter should exist in our cosmic space in the form of antimeteorites how would we extract it and deliver it to earth in such a manner that it would not be coming in contact with matter? This problem appears to be very difficult and possibly even in general insoluble. But life teaches us that a number of processes which were regarded as improbable have nevertheless been realized. One should not forget this.

In concluding the scientific aspects of discussing the problem of supplying mankind with energy in large quantities I shall touch briefly upon one social and political aspect of this problem associated with its global nature.

It is quite evident that all global problems will have to be solved on an international scale. The principal difficulty in realizing the required solutions will consist of the fact that their demands will often conflict with interests of individual countries. The principal social–political problem reduces to the question of how the interests of individual states can be subordinated to the interests of mankind as a whole.

Here a number of opinions have been expressed. Some people consider that this is in general unrealizable, that complete freedom must be provided for the development of human culture. Until now in the course of millions of years mankind by means of trial and error has itself found the path towards the development of civilization. And it will find such a path again.

Another opinion, a more constructive one, as many justly consider, is that the necessity of solving global problems will lead mankind to build a society with a socialistic structure, and that only with such an organization of society will it be possible to make compatible the interests of individual states with the interests of mankind as a whole[8]...

For the solution of global problems it is necessary that a number of sectors of world economy associated with ecological problems should come under international control. There is a tendency towards this already. For example, with ever greater frequency appeals are heard that the exploitation of the world's oceans and, in particular, the extraction of raw materials from their depths, should be controlled by the United Nations.

It is also becoming necessary to solve the problem of the supply of energy and the utilization of energy resources on an international scale. This has already begun to be realized in the creation of the International Atomic Energy Agency whose principal function is the control of resources and of the safety of utilization of atomic energy on a global scale.

An effective solution of global problems will become possible only if their significance for the fate of humanity will be widely understood by people, and this is possible only if these problems receive wide discussion. Therefore scientists must take care that the discussion should be carried out on a strictly scientific basis. Of course, the solution of global problems must be based on the ethical obligations of man toward society.

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[8]P. L. Kapitza, Voprosy filosofii (Problems of Philosophy) No. 2, 37 (1973).

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Man and environment—problems of the future

E. K. Zavoĭskiĭ, B. B. Kadomtsev, L. B. Okun', and B. M. Smirnov

I. V. Kurchatov Atomic Energy Institute; Institute for Theoretical and Experimental Physics, Moscow

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In our time of rapid scientific-technological progress specialists in narrow fields of science can no longer not participate in the discussion of more general problems of the development of science, technology and production and of their effect on the development of human society. There exist two main global problems which relate to our whole planet and which in the foreseeable future will affect the conditions of human life. The first of them is associated with the depletion of natural resources, with this occurring against the background of increasing numbers of population. The other problem is due to the effect of man on the environment. As production increases this effect is intensified and, if it is not controlled, then the pollution of the environment will rapidly exceed admissible limits.

Let us consider these problems in greater detail. As regards natural resources, with present rates of growth in the extraction of useful minerals man is capable within the next one–two hundred years of exhausting many of them. The present methods of energy production are based on chemical types of fuel: the burning of coal, oil, and gas produces approximately 95% of energy. At the beginning of the next century the role of atomic, and then of thermonuclear energy production will have to increase sharply in importance. For the operation of transport it is proposed to develop energy production based on hydrogen. It is based on artificial fuel (for example, hydrogen) which is produced utilizing atomic and thermonuclear energy and which is used in the same manner as gasoline is used at present. In this manner we possibly shall encounter a peculiar situation when mankind shall have to pay for the scarcity of certain useful minerals by a still greater increase in the production of energy. However, energy is not a universal substitute. And the problem of creation of new materials, the search for new technological processes, the problem of recycling of materials all become very pressing ones.

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