575.1 P.G.3586

B86A Brondsted, H.V.

Atomic age and our biological future 1957.

THE ATOMIC AGE AND OUR BIOLOGICAL FUTURE

The Atomic Age and Our Biological Future

H. V. BRØNDSTED

WATTS
40 DRURY LANE LONDON

FIRST PUBLISHED IN 1957
by C. A. Watts & Co., Ltd.
40 Drury Lane, London, W.C.2

Translated from the Danish, *Atomalderen og vor biologiske fremtid* (Hans Reitzelts Forlag, Copenhagen, 1956).

Printed in Great Britain by
East Midland Printing Co. Ltd.
Bury St. Edmunds, Peterborough
and elsewhere in the U.K.

CONTENTS

FOREWORD

THIS book is written in a popular style because its aim is to give to a wide variety of people an opportunity to review for themselves what is happening to us in the atomic age. It seems to me that it is necessary for broad sections of the population to be informed of the risk to which we expose mankind in having recourse to the power of the atom in our struggle for existence. It will then be easier for the individual to contribute towards lessening the risk and to make up his mind about the many social problems that will inevitably arise.

Introduction

THE atomic age—this phrase suggests the romance of man's breaking through the closed door.

Among the many folk-tales that have passed from land to land, from age to age, and are man's common heritage, imbued with the wisdom of generations, one remains a symbol of man's inquiring instinct—the fairy-tale of the one door that the prince must not open. All the other doors are permitted, for they lead only to the small surprises, variations of the known. But behind the forbiddden door there hides the totally unknown: the winged horse or the wizard; untold treasures or the wonderful princess. Yet in a strange fashion catastrophe is bound up with what awaits him there. It is the tree of the knowledge of good and evil, ready to tempt and decoy.

And the fairy-tale tells the truth. When the great pioneers, Röntgen, Curie, Rutherford, and others between them turned the key in the great door and managed to push it ajar on its powerful hinges, the rays broke through the chinks to dazzle, to lure and to draw them in. The door was pushed open a little more, the flood of light burst forth, healed many that were sick but burned many of the sound and well. Thanks to Niels Bohr with his associates in the work and his pupils the door is now wide open and mankind pours through it. We are able to capture new forces, and they can be harnessed, governed, and put to use. Can our research and our knowledge protect us against the catastrophe which, as the fairy-tale suggests, is bound up with those untold treasures?

Mankind on this earth of ours is now a multitude of close on 2,600 million souls, and the number increases by about 20 to 30 millions a year. If all these mouths are to have food enough, if all these men, women, and children are to be clothed—no matter how slight their needs—if all these families are to be housed, however modestly, then assuredly we cannot solve the enormous problems without mechanical power in every form. At present the technical energy at our command is more than a thousand times greater than the collective work of human muscles.

This energy will not suffice for very many years. Everyone knows that resources of coal and oil will be exhausted comparatively soon. Even if solar energy in various forms can be utilized far more efficiently than is the case at present, that will still not suffice; there remains only atomic power.

Everybody, then, must rejoice to hear that the Congress on Atomic Energy, held in Geneva in August 1955, was able to unite all the nations in a joint endeavour to discuss in a tolerably open manner the theoretical and practical problems relating to the exploitation of atomic energy. So with banners flying and drums beating we have entered upon the atomic age. Once more theoretical science in its own 'ivory tower' has enabled mankind to subdue the earth, has put into our hands the means to carry out the good works of peace by satisfying the hunger of many mouths. That, with all this, science has given to man the power to exterminate himself is not the fault of science.

Apart from war, however, the atomic age involves two basic perils for mankind. The one amounts to the fact that men may have too little to do. We shall run the risk of being flooded with industrial products of every kind for lightening toil and especially for enjoyment in everyday life; many will grow weary of such a mass of playthings.

It will be a colossal problem for far-seeing folk who have imagination to keep people occupied in such a way that their urge for action does not end in working itself out at others' expense.

The second peril to be faced is that we are in danger of releasing forces that not only bear upon our minds, upon the personal reaction of the individual human being to the new forms of existence, but that also reveal very different perspectives, more profound and violent—perspectives compared with which the wars of religion, the most destructive civil wars, the two world wars, all those frightful happenings we hear about in the history of mankind, will appear as trifles, ripples on the sea of destiny enfolding all mankind.

For we are releasing those forces which through the earth's history of three thousand million years calmly and silently have shaped our destiny out of the primeval sea, to form that being who now, having partly freed himself from the bonds of nature, attempts to take destiny into his own hands, yet without the power completely to control it.

What sort of forces are these we have let loose? They are radiated energies that can destroy single individuals, that can have the effect of deforming many embryos, that can cause sterility, and that—most dangerous of all—may influence our reproductive cells and thereby alter the genetical constitution of future generations. It is this book's mission to explain how these effects may come about unless to the utmost of our power we keep in check the forces of the atom.

Most readers of this book enjoy the sovereignty, more or less, of the independent individual, and are therefore under the impression that we take a share in determining the future of mankind, each one of us contributing our mite. And so it is in the cultural and ethical spheres. But our capacity to influence or determine mankind's genetical constitution in the future is extremely slight. It is limited to avoiding reproduction of certain objectionable characteristics by means of sterilization and similar preventive measures. As individuals we feel that in some degree we are masters of our own destiny, and through reciprocal influences in conversation, through writing, pictures, radio, and so on we decide to a certain extent the structure and forms of activity in our community. Yet the basis of all this action is outside our control. What happens in the course of sexual reproduction, or during the formation of sex cells, life's deepest essence, is not an individual matter, even if we believe it to be so when we choose our partners in the sexual act. Reproduction is the affair of life itself, the individuals are only instruments for transmission of the living substance through the ages.

Life itself is just one great game of chance, life carries on an incessant struggle against the hard world, moves forward tentatively under shifting conditions to find possibilities of survival. It is mutation, the power within the life processes to transform themselves, that has made possible the continued survival and transformation of life. We are now in danger of increasing artificially the speed of mutation in ages to come and with that we risk some disturbance of our biological equilibrium.

A well-known radiologist, who during the many years of his great curative work was exposed to radiation, declared recently that the risk from X-ray irradiation to his own genetical constitution did not seem to him worth considering, for he had, after all, produced three healthy boys, who were clever too. This utterance by a doctor was one of the factors which determined the writing of this book, for it shows that the latest conquests of biology in this most central field, mankind's genetical future, are not yet sufficiently known and understood.

The atomic age confronts us with an altogether new ethical problem: Are we responsible for the men of the future, for distant generations in days to come? We are accustomed, in our individual existence, to feel a responsibility for our neighbours and for our children's future; we help them to the best of our ability, on the ethical as well as on the economic plane. This sense of responsibility, however, has its roots both in the biological side of our being and in our acquired cultural state. Very few people give any thought to their genetical constitution, and then only if there are in the family notorious heritable defects of a physical or mental nature. If there are not, we cannot feel responsibility for our children's genetical constitution, for we cannot influence the composition of the genetical units in our sex cells, and we are equally without influence as to what genes might chance to unite in the fertilized egg cell. Nature has apportioned our genes, some of them ages old, springing from the origin of life on this earth, others later in arrival, some of quite recent date. The new situation came about as a result of the fact that we can now raise artificially the frequency of mutation and thus can produce artificially a new genetical constitution.

We are therefore responsible for some of the mutations that will place their stamp on mankind in future generations —not for the nature of the mutations, but for their actual emergence. Later we shall hear about the harmful character of the great majority of these mutations. We are therefore in danger of bringing about, through our manipulation of atomic energy, a deterioration in future generations of mankind, even if, like the radiologist already mentioned, we too see no ill effects from radiation on our own children.

In education there is always a way back or aside or forward, if the education has proved to be wrong. If the social order is bad, there is always a possibility of having it altered into something that seems better. But there is no way back if in our ardour and imprudence we have altered our genetical constitution, whether it be for better or for worse, and the chances are by far the greater that it will be for worse. That is our new and immense responsibility. Are we going to admit this responsibility?

We wish to give our descendants a life in good social conditions. Do we also wish to do what we can towards ensuring that our descendants shall be as well equipped genetically as we ourselves are? Or is that no business of ours? Do we feel satisfied with giving our descendants the power and resources to curb primitive forces for technical advantage, while at the same time we disclaim responsibility for their genetical health?

Responsible biologists have raised these questions amid the enthusiasm with which we greet atomic power. Can the sense of responsibility in the nations of the world be aroused with regard to these questions? Only through enlightenment. It is the task of this book to show why we are confronted with this responsibility.

CHAPTER I

Radiation

THE word *rays* has a very specially suggestive force that is rooted in the fact that from the cradle to the grave we feel the sun's blessed warmth, but also its scorching energy; for we turn fire to our use, yet fear its power; we are fascinated by the moon's cold light; we are guided on our way by the eternal stars. The idea of radiation is mingled in with our very being and thus imbued with mystery, inextricably bound up with more primitive religious conceptions; it has become an indispensable component of much that moves us in art; and now it is caught up in the sphere of the intellect and has become for science an object of penetrating research; research whose results are as stimulating to curiosity and challenging to the imagination as they are pregnant with destiny for our future.

Let us hear in quite everyday language a little about these results.

Some of the ancient Greeks had formed the opinion that the universe contained countless objects of varying size, shape, and nature, all of which, however, were divisible into smaller and smaller objects, until parts so small were arrived at that it was impossible not only for them to be further divided in practice, but also even to conceive of their becoming any smaller; the smallest parts were *a-toms*, a word that literally means indivisible.

Science in the nineteenth century reached the same result. People thought that all matter consisted of indivisible particles—atoms. Then, however, about the turn of the century came the great romance of the discovery of radium, 'the radiating substance', as the word radium implies. Incontestable proofs were found to demonstrate that the atom could be split! In spite of that, the old familiar name, atom, was retained, but it acquired a different sense; the word atom now signifies the smallest unit of an element that can exist and yet preserve its character as an element.

The word element, too, suffered damage to its meaning in the light of the discoveries of modern physics.

The sorcerers and alchemists of the Middle Ages dreamed of the Philosopher's Stone, which could change all metals into gold. The dream was abandoned by the chemists of the last century, who were of the opinion that substances such as gold, copper, iron, sulphur, oxygen, and hydrogen, together with some ninety others, were unalterable in their essence, even if to all appearance they altered their properties by uniting with other elements to form chemical compounds, such as verdigris, rust, sulphuric acid, or water. They were therefore called elements. But the dream from the Middle Ages took on a new lease of life with the discovery of radium, and now we know that all the elements can be transformed into others. Yet the word element was retained even so, because it indicates a certain stability in those substances which had formerly been regarded as unalterable, a stability which is turned to good account in ordinary work with chemicals.

Only one of the elements actually deserves this name, the gas called hydrogen, the lightest of all substances, the substance from which, at all events in theory, all the other elements may be built up. But even the atoms of this substance, which after all is still perceptible to the senses, are divisible; for if we split a hydrogen atom we are really no longer dealing with a substance, but with energy, with electricity, and this of two kinds, positive and negative.

Thus modern physics has shown that matter and energy are just different manifestations of the same thing. We must in future reconcile ourselves to the idea that matter is one of the impressions that energy conveys to our body when we use the senses.

But what, then, has all this to do with radiation, which was really our special topic?

Everything. For energy manifests itself as radiation when it moves in space. And it can do this in two ways—either with a motion that can be described as waves, which are propagated in space and time, like waves on the water, or as a string of energy bundles travelling through time and space. It is therefore usual to distinguish between two kinds of rays, waves and particles, the latter being bundles of energy. Whether radiation may be described as of a particle or wave nature depends solely on the experimental procedure.

Light may be described as electro-magnetic waves which are transmitted through space at a speed of 186,000 miles per second. It can also, however, be described as infinitesimally small bundles of energy, *photons*, which of course are hurled through space at the same fast rate. The two methods of description are mutually exclusive in the same experiment; as Niels Bohr expresses it, they are complementary.

How is energy liberated as radiation? For some understanding of this a slight knowledge of the structure of the atom is required.

A hydrogen atom is formed of a bundle of energy, which is composed of negative electricity that flies at a furious rate round a bundle of energy formed of positive electricity. Like all other negative and positive electricity they attract each other, but owing to the tremendous speed of the negative there is equilibrium between the power of attraction and the power of discharge. We can use a rough illustration.

We fasten a stone to one end of a spiral spring, we hold the other end firm and swing the stone round. The spring stretches until the centrifugal force of the stone is exactly balanced by the tension in the extended spring.

The negative electricity in the atom has been named an *electron*, while the positive is termed a *proton*. The distance between the two bundles of energy is so slight, the whole diameter of the hydrogen atom so small, that some ten millions of them would have to be ranged in a row before a millimetre is covered; but the bundles of energy themselves are so infinitesimal in extent that their size in proportion to the atom would correspond to a couple of tennis balls at a distance of one kilometre from each other. And yet they are bound to each other by forces that are strong by comparison with their size.

Now an odd thing can happen to an atom if we play with it. Suppose we impart to it a certain energy from outside, the electron can absorb this energy, it becomes more lively, puts on a greater speed, and springs into an orbit that is farther out; just as the spiral spring will be stretched still more if we swing the stone round faster. It has been calculated that the amount of energy needed to move an electron one orbit farther out is the smallest amount of energy that can exist independently, and it has been named a *quantum*. One peculiar feature in this game is that the electron cannot be made to oscillate in all orbits, it is tied to certain definite ones, like a tram-car, which must follow the lines, and not like a bus, which can accommodate itself to the traffic by moving slightly to one side or the other.

The electron evidently does not like swinging out into an outer circle, for when there is a chance it springs back into its old orbit, but in doing so it will let go its hold of the energy that has been added to it, that same amount of energy that made it move outward; and the energy quantum thus liberated makes its appearance as light, which may be described as a photon or as an electro-magnetic wave, according to the manner in which we have carried out our experiments to capture the energy.

If several hydrogen atomic nuclei are made to fuse, larger atoms will, of course, come into being. This is the way we picture the origin of all the other elements, and through astronomical observations it is known that this happens out in space, thus gradually causing the birth of new worlds. There is perhaps a vast cycle between birth and death. It may be that atoms of the dead spheres are split into hydrogen nuclei, from which new spheres are then formed. Yet an altogether staggering idea has been propounded by well-known astronomers, staggering because it breaks away entirely from our ordinary conceptions. In all seriousness the theory is advanced that hydrogen atoms spring from nothing, absolutely nothing. I am not going to philosophize on this subject here; I am only mentioning it because it shows to what extent modern physics is capable of disengaging itself from the particular orbits in which the thoughts of all of us rotate, our thoughts being dependent —in the last analysis—on our daily sense impressions.

An atom, which consists of many protons in the nucleus, attaches electrically to itself the same number of negative electrons as the positive protons it holds. Let us take an example. Nitrogen is the gas that makes up 78 per cent of the atmosphere above us. One nitrogen atom has 7 electrons circling round it, and therefore has 7 protons in its nucleus. But there is more in the nucleus than protons. There are also portions called *neutrons;* they are so named because they are electrically neutral, they are neither positive nor negative. Together with the protons they give the nucleus a mass that is immense in comparison with the mass of the electrons. These particles are held together in the nucleus with enormous amounts of energy, far, far greater than the electrical forces that hold electrons and nuclei together. The nature of these forces is as yet unknown.

If the nucleus breaks up, a portion of this enormous energy may be liberated; this is precisely what happens when the uranium nuclei in the atomic power stations are split into smaller nuclei. Some of the energy is liberated in the form of particles and in this case it is the neutrons in particular that arouse our interest. When the neutrons are hurled out of the split nucleus, they carry great energy with them, just as the shot does from a cartridge that is fired. Some of them go slowly, others fast, and the depth of their penetration into the substance they happen to strike depends on their speed. If it is living matter that receives this bombardment, frightful things often happen in consequence, about which we shall hear later. But energy in other forms is liberated also, for instance, as electro-magnetic waves of great penetrating power, and these are the so-called *gamma-rays*. Sometimes protons are also ejected; thus when radium decays *alpha-particles*, which consist of two protons and two neutrons bound together, and are identical with the helium nucleus, are emitted. And finally, masses of electrons are hurled out of the nucleus; these are called the *beta-radiation*.

All these kinds of radiation influence all other matter that they strike. For they are all forms of energy, and we have heard more than once that something happens to the atom when energy is imparted to it from outside. Naturally it will depend on the magnitude of the energy whether what happens to the bombarded atom is something absolutely frightful, that its nucleus is shot to pieces, or if there are only some vibrations in the atom, perhaps so powerful that one or more electrons are shot away. As protons and neutrons in the nucleus are attached to one another by very strong forces, it takes an immensely powerful bombardment to split up the nucleus. That is done, too, in the atomic power stations, where the heavy radio-active nuclei break up and where some of the liberated energy can then shoot other atomic nuclei to pieces, in the so-called chain reactions. When a big shell explodes and its fragments strike a heap of broken stones, some of the stones fly round and perhaps hit a window-pane, the splinters from which may in their passage cut someone's face. Just as the energy of the shell in this analogy is by degrees widely dispersed and in the process scatters pain over a very large area, so that the energy is somehow absorbed and apparently fades away into nothing (it is converted into heat), in the same way the radiation from the processes of the atomic nucleus is by degrees absorbed by all the matter it strikes. But on its way, like the shell, it may indeed before coming to rest have caused many disasters.

The most powerful effect, however, strikes only the matter that is close to the site of the explosion. On an average it may be said that for every time the distance from the explosion site is doubled the intensity of the radiation decreases four times. That is why we only see the radiation from distant stars when the night sky is dark, although these stars may be many times larger than our own sun, which injures and dazzles our eyes. If there are diseased cells in our body, which we seek to destroy with rays from the X-ray apparatus or from radium, or from other sources of radiation, we must measure the distance from the radiation source to the diseased spot and adjust accordingly the penetrating power of the radiation; this power depends on the strength and nature of the rays.

Yes, their nature, for here we are concerned with a matter of great importance for our understanding of the effects of radiation. I must therefore say something about it.

Broadly speaking, radiation may be divided into two main groups, the corpuscular (corpus=body) and the electro-magnetic wave. This division is convenient, but, as already stated, whether we are going to talk of particles or waves really depends on the mode of procedure in experiment. First, then, a little about the corpuscular group.

The alpha-particles, as I said before, are helium nuclei, consisting of two positive protons and two neutrons bound together. Because they are positively charged they react vigorously with the substance they pass through, stealing the negative electrons of other atoms and flinging them around; but this reckless activity soon absorbs the whole of the energy in the helium nucleus; at last the nucleus checks its race (the velocity of that race is approximately 12,000 miles per second), and now it goes on with a quiet life like a normal helium atom, henceforth contenting itself with the two electrons it has snatched from other atoms on its way. This consumption of energy is rapid, so rapid that the helium nucleus can only pass through about three and a half inches of ordinary air.

The beta-radiation is composed of negative electrons. We have heard that their mass is quite infinitesimal in relation to that of the atomic nucleus. If they are to assert themselves they must attain very high velocities. A grain of sand that gently falls upon the face when we are lying on the beach is hardly noticed. But grains of sand that are chased along by the storm can bore a hole in our skin. The speed of the electrons can rise to very nearly that of light, which, as already mentioned, is 186,000 miles per second. Such swift beta-rays can penetrate several yards of air, but only because the air molecules are composed of atoms with fairly small nuclei. If the electrons strike, for example, lead with large and heavy atomic nuclei, they are very quickly checked. Everywhere on their way, however, they create disorder in the electrical conditions in the atoms. If the beta-rays are slow, they are of course checked even by light atoms. As their velocity depends on the force with which they are hurled out, it is understandable that very great amounts of energy are needed for the generation of swift beta-radiations. If electron rays are to be used, for instance, in the electron microscope, the microscope tube must be pumped free of air, because otherwise far too much energy would be used up in hurling the rays through the air, and that is a costly business.

Then there are the neutrons. They are detached when a nucleus breaks up. They are electrically neutral, so they are not checked either by positive or by negative particles, either by atomic nuclei or by electrons, they simply do not care to associate with them, they run straight through. When, even so, they are by degrees pulled up, it is because they cannot avoid striking the atomic nuclei themselves from time to time with a direct hit. If they strike right in the bull's-eye they are arrested altogether; then perhaps they force their way into the nucleus and their kinetic energy is converted into electro-magnetic waves, which, as we are to hear later, can do harm. If they only give a push to an atomic nucleus, as if to a billiard ball that ricochets against another one, the other is shaken slightly, and consequently emits electro-magnetic waves. Naturally the happy-go-lucky neutron also, which passes through matter, may push electrons away from their place round an atom nucleus, and that introduces disturbances of an electrical nature into the whole ménage, because the detached electrons must seek out other resting-places; they may even be caught up by other atomic nuclei and as a result the electrical equilibrium will be upset elsewhere in the substance. Despite the fact that the neutrons cannot themselves react electrically with other atoms, they manage even so to create serious trouble, just as a dog overturns the skittles in a skittle-alley, although it has no inkling of the rules of the game.

Next there are the electro-magnetic waves. Many of them we know from our daily life: radio waves, infra-red, light, ultra-violet, X-rays. The difference between them is that they each have a different wave-length. The radio waves are from over 1,000 metres to a couple of millimetres, the infra-red from that down to a thousandth part of a millimetre, visible light about a two-thousandth part of a millimetre, and X-rays are everything below that. Those X-rays which have the shortest waves of all are called gamma-rays, and they are emitted in large amounts at the particular moment when atomic nuclei explode, whether that occurs spontaneously, as in the radio-active substances, or as a result of the bombardment of atoms by very powerful energy influences, e.g. by neutrons. But it is important to realize that the limits stated for the various kinds of waves are on an arbitrary assessment, since in reality there are quite smooth transitions from one region to another. A feature common to them all is that they are transmitted in a vacuum with the speed of light, 186,000 miles per second. Their enormous difference in effect on the substance they penetrate is therefore due, not to a difference of speed, but to that of the wave-length. The shorter the waves, the more easily they penetrate, because their energy increases with the shortening of the wave-length. Thus ultra-violet rays penetrate farther into living tissues than light, X-rays farther than ultra-violet, and gamma-rays still farther in. The *cosmic rays* contain electrons and positrons, neutrons, protons, mesons and possibly other things; but they also contain electro-magnetic waves, gamma-rays, having so short a wave-length that they can penetrate through thick layers of water or thick plates of lead. The shorter the wave-length of the rays, the 'harder' they are said to be.

What do the electro-magnetic waves do to the substance when they penetrate it? They too, of course, cause disturbances in the electrical conditions in the atoms, first and foremost by making the electrons leap over into other orbits or by detaching them entirely from the atomic nucleus.

Thus, most types of radiation cause electrical disturbances in atoms. When this disturbance is great enough to detach or add an electron to an atom, it is said to ionize, i.e., to produce *ions*. What are ions?

When I was young the expression Jon, a johnny, was applied to young persons of the male sex who used to stroll up and down our main street in foppish garments. The word ion is of Greek origin and means one who walks, a rambler. And an ion is neither more nor less than a particle that rambles, this time in an electrical field, because it is itself electrically charged. Now what does that mean? We have heard that an atom is electrically neutral if there is equilibrium between the number of negatively charged electrons and positively charged protons in the nucleus. The atom is, so to speak, 'satisfied'. But if we take away one or more electrons, the atom in relation to its surroundings becomes positively electric, because it has lost negative electricity, and it is now termed a positive ion. If one or more electrons are added to it, it becomes negatively electric in relation to the surroundings—it will be a negative ion. In both cases the atom could be described as 'dissatisfied'. In the first case it needs to be satisfied with negative electrons, in the second case it wants to get rid of electrons. And as there is enough and to spare in the swarm of atoms in the surroundings, depredations occur, which are called chemical processes.

Now it happens as a rule that those atoms which have had electrons taken away from them or added to them have been bound together with other atoms into larger units, which are called molecules. For example, two atoms of hydrogen are bound together with one atom of oxygen into one molecule of water. This binding is managed through a fraternal system in which the electron charge is shared among the nuclei—not that the electrons break up, but in such a way that their negative electricity contributes towards satisfying the positive charge of the nuclei. All other substances, too, are built up from molecules, in which the atoms are bound together by means of the electrons. Any molecule will therefore become an electrically charged ion, if one or more electrons are removed from or added to the molecule, and as soon as that has come about the molecule can go through chemical reactions.

And now we understand how radiation can work so much havoc when it passes through a substance. For the whole calm and quiet life that the molecules have led hitherto is now thoroughly upset, so much perhaps that altogether new molecules come into existence when the ions have reacted with other ions.

Now if the substance that is bombarded by rays consists of molecules with a very complicated structure, this substance may be entirely changed by radiation. And if these molecules in peace and quiet have played with one another in a pleasant, orderly fashion and in regular patterns, then all of this is completely disorganized and the games come to a standstill, or rather, the ions tumble over one another topsy turvy, until somehow or other the playing-field settles down. By that time, however, the molecules may be so altered that they can no longer make any sense of the old games. New chemical compounds have arisen. That is what happens when powerful radiation strikes living matter. The latter is so complex in its interplay of molecules that it will not be long before the game is broken up, and if things are really serious the matter must die. That is the way cancer cells are killed by radiation; but it is also how cancer is caused; and that, too, is how radiation can bring about malformation of embryos and, worst of all, produce new genetical characteristics, which will almost always be of a harmful kind, harmful mutations.

It will be evident to the reader now, I hope, that the more powerful the radiation is, the greater the chances are of drastic chemical change in the substance exposed to radiation. It is therefore of the greatest practical importance that the strength of the radiation should be capable of measurement; but, as the nature of the radiations varies so much, the units of measurement must be determined by the effect of the radiation. For the unit of measurement the choice fell on what is called a *röntgen,* which is written down simply as *r.*[1]

To indicate the explosive energy of the atoms the unit of measurement 1 *curie* is used (named after the Curies, who discovered radium); that is the energy which is liberated from radio-active material if the nuclei explode at a rate of 3.7 x 10,000,000,000 per second. As this amount of energy is enormous, in ordinary practice the unit of measurement *millicurie* is used, which is a thousandth of a curie. It is often difficult to convert this energy force to *r,* especially where living matter is concerned.

But in order to understand how radiation acts on living matter, we must hear something about how that matter is organized.

1 One *r* is the strength of the radiation which in 0.001293 grams of air detaches a particle that is charged with a positive or negative charge of 1 electrostatic unit.

CHAPTER 2

The Fertilized Egg

OUR body is composed of many milliards of small units which are called cells. A cell, therefore, is microscopic. On the under-side of the finger-tips can be seen a fine pattern of long ridges divided by grooves, those which make the 'finger-print'. The distance from groove to groove over the ridges is about half a millimetre. We can form some idea of the size of the cell when we realize that in this short span there are 20 to 50 cells side by side. In a single drop of blood there are many millions of cells. The human brain alone contains about fifteen thousand million cells.

A normal cell consists of a viscous, semi-clear substance called cytoplasm; inside it there is a small fluid-filled vesicle called the cell nucleus, which is separated from the cytoplasm by an infinitesimally thin film, the nuclear membrane. The whole thing constitutes an incredibly complex chemical factory, as it were, the sum total of its chemical processes manifesting themselves as the vital activity of the cell. The cell nucleus is the centre of the whole factory. It contains a number of threads, in human cell nuclei 46 (according to the most recent calculation), which control and direct the metabolic processes in the cytoplasm. The threads, which are generally invisible, even under the strongest microscope, may be compared to strings of beads. Each separate 'bead' is a little chemical laboratory having its own quite distinct characteristics and tasks. These 'beads' are called *genes,* which means 'those which produce something'. The genes are the hereditary units that see to it that our body develops actually into a human body, from its very first beginning as a fertilized egg. We do not know how many genes a human cell contains, but there are at all events many thousands of them; not only are they different from one another, these genes, but some of them are different from corresponding genes in other people. This variation is so enormous that no one person has the same genes as anyone else, and therefore two people are never entirely alike—with the exception of identical twins, who have the same genes because they come from the same fertilized egg.

The sum total of the chemical processes that the genes of an individual can set in motion is called his *genotype*. This genotype is given to the egg when it is fertilized by a sperm cell, and cannot be altered.

All this, of course, is not easy to understand for anyone who has not given attention to the subject; so I will now try to describe the whole process with the aid of a model to illustrate it.

The fertilized human egg is a comparatively large spherical cell, although it is only a little more than a tenth of a millimetre in transverse section, hardly visible to the human eye; yet it contains within its bounds the whole chemical machinery that initiates the development of a human being.

It is always hard to think according to an entirely different scale from the one to which we are accustomed. It may be difficult enough for an ordinary taxpayer, who must look twice at every shilling, to understand the way in which millions are handled in administration. But it is still more difficult to go in the opposite direction and to visualize a prodigious multiplicity on the very small microscopic scale, a scale, indeed, which is far below what can be seen in the microscope. But all the same, let us make an attempt with the aid of a model for illustration, and let us begin with the atoms.

A hydrogen atom, as has been explained, is constructed of two centres of force, a positive nucleus and the negative electron. For the sake of simplicity we may picture the atom as a little ball, the diameter of which is close on a ten-millionth part of a millimetre. It may be hard to imagine this scale, just as it is hard really to imagine ten million pounds sterling. But let us try. If we make the ball that is to represent the hydrogen atom 1 centimetre in diameter, something like the marbles children play with, then 1 million balls placed in a row will reach a length of 10 kilometres. If we apply this scale to the human egg it will form a ball of fully 1 kilometre in diameter. And now let us have a look at this.

Besides the hydrogen atoms there are atoms of about thirty other kinds of element in the egg, and they are all a little larger than the hydrogen atoms. We can picture to ourselves the atoms of the various elements in the form of marbles of various colours. At a rough estimate their number in the egg can be reckoned at some billions! That, of course, is a number that does not make sense; but if we picture the egg as a ball 1 kilometre in diameter, and see that it is composed of variously coloured marbles which are so close to one another that they almost touch, then perhaps we can, all the same, form some idea of the number. The wonderful part is that the whole thing is so beautifully organized; not that the balls are motionless as in a mosaic, for the majority keep rushing round, but many of them do this in definite orbits. It is mostly the water molecules that rush round; they consist of 3 marbles: 2 hydrogen atoms and 1 oxygen atom; but salt molecules of various kinds, e.g. common salt molecules—1 chlorine and 1 sodium atom tied up with their electrons—rush round also. There are, however, some very large molecules which have fairly definite places in the ball; these are the albumens, certain fatty substances, and some others. If we look more carefully at our large kilometre ball, the egg, we find that the small marbles in many places are joined into clusters or strings which form definite patterns, structures like carefully built machines, in which the molecules are composed of many hundreds or thousands of atoms bound together into one firm unit—always by means of the electrons on the surface of the atoms. It is these machines that play with the loose atoms and small molecules and ions, that rush round among them more or less fortuitously. And they play with them in such a way that they catch some of them and bind them to themselves in their own pattern, while at the same time they let go their hold of others. It is this game, this chemical activity, that is called metabolism. And the game is highly organized, even more so than folk-dancing, with its quadrilles or its chains or whirling couples. These organized games are the vital processes themselves. The wonderful part here is that a certain organization prevails in the game with atoms and molecules played by those many millions of machines. It is that game which makes it possible for the fertilized egg to develop into a human being.

In the centre of the large kilometre ball there is a domed hall, the egg nucleus. Inside it there are 46 long strings formed of protein molecules, and to them other molecules of special substances are attached, lying in clusters along the protein chains. We have only a rough idea of how these large molecules are constructed and how they work. But we know that they are the chemical laboratories which somehow or other control and determine how the machinery outside the nucleus, out in the cytoplasm, is to be organized, and how it is to operate. The first impression of our kilometre ball is of an utterly confused running this way and that among small and larger groups of atoms, molecules, and ions—in our illustration groups of differently coloured marbles. It is just as a view over a city from an aeroplane gives the impression of a confused and aimless going to and fro of cars, bicycles, and pedestrians. In both cases, however, closer observation reveals that there are definite main thoroughfares and certain buildings from which and to which there passes a steady stream of molecules or people.

It may be hard enough to survey to any extent the activities of a million people in a city, but it is quite impossible to obtain a really comprehensive view of our egg, where there are several billions of individual beings. How the atoms unravel themselves in the egg is the big riddle that biochemists and biologists are attempting to solve. Provisionally we can only say that it must be the work of the comparatively few chemical centres—though there are millions of them existing in the egg.

One might think, indeed, that all this incomprehensible machinery could easily break, nor would it take much to bring that about. If we apply heat up to 45° to 50° C., all the molecular movements become so lively that much of the machinery falls apart, and then the organized game ceases; we say that the egg dies. Or we can put the egg into a strong salt solution; then the water molecules rush out of the egg and it shrivels up and dies; or we can put it in pure distilled water, when millions of water molecules will rush into the egg, so that it swells up, its chemical machinery is torn to pieces, and it falls apart and dies. The life processes, therefore, can only operate when the outside conditions keep within certain limits.

But now we come to the rays. We understood in the first chapter that radiation imparted energy to the atom. How are we going to form a clear picture of what happens when radiation strikes an egg? Once more we shall have recourse to our giant model, the kilometre ball, composed of the countless swarms of marbles. We can imagine a violent storm lashing the countryside. The hurricane rages against the ball, hurls tons of hail and sand against the mighty structure, squeezes its way in through the chinks between the marbles, actually breaks away the outer shell from many of them, so that the fragments of shell (the electrons) fly round among other marbles and detach new fragments of shell. Some get a direct hit from the hail, and then they shake and vibrate so much that other shell fragments are detached, the so-called secondary effects of radiation. All those ingenious machines have difficulty in holding together under the fury of the storm; greater and greater grows the havoc under the pressure of the onslaught of hail. Now the hurricane stops as suddenly as it came; we find everywhere shattered and changed molecular machinery. If, however, we look at the whole kilometre ball with a superficial gaze, it seems as though nothing has happened; the ball is there in its entirety, there are movements everywhere, much of the molecular mechanism is apparently intact. Only a close inspection shows that the game of the marbles is not as it used to be; in many places the chemical machinery is working in the wrong way, or it may have fallen apart in many pieces. The pieces work by themselves for a while without being able to make proper contact with one another, coordination is lacking, soon it becomes impossible to find sense or design in the whole collection of chemical games, and the egg dies.

This is the result of powerful radiation, whether it is composed of X-rays or gamma-rays alone—we might then compare it with a 'dry' hurricane—or contains also hail (alpha-particles and neutrons) together with grains of sand (electrons, beta-radiation).

Like all comparisons, this one too is defective in regard to some vital points. One of the most important differences is that radiation passes through the living cell with far less obstruction than the hurricane would meet in squeezing its way through our kilometre ball. It is this which makes radiation so dangerous, because it can easily reach fundamental and vital chemical centres inside the ball, moreover without doing so much harm externally; just as a bomb on the headquarters of a large army is enough to paralyse the organized movements and operations of that army.

The headquarters of the egg, as we have heard, are inside the cell nucleus. Here there are 46 molecule strings, the chromosomes in our kilometre model confined in a central section, a special domed hall, about 200 metres in diameter. We see these strings, then, like ropes perhaps a few metres thick formed of glass balls ingeniously put together; they wind their way in long curves into the domed hall. If we look more closely, we find that they match in pairs, except for two of them in an egg that is to develop into a man; there numbers 45 and 46 are a little different, they are called X and Y chromosomes; in an egg that is to develop into a woman there are two X chromosomes.

Each of the ropes is constructed like the knotted ropes we climbed when as children we played in the gymnasium. Some of the knots are small, perhaps only very few metres on an average in our model, others average many metres. We cannot keep count of them, but there must be between 25,000 and 100,000. These are the *genes*. Together with the molecule ropes on which they rest, these atoms and groups of molecules go through the strangest motions, which are carried out with extraordinary precision. The result of these reciprocal motions and developments is that impulses (electrons) issue from each knot into the surroundings to other molecules in the nucleus, impulses that result in the emergence of these others from the domed hall as new molecular structures, which have their own precise motions. And when they come outside the domed hall they reorganize much of the game that is proceeding here and make up new games, link up different groups of molecules into new patterns, while all the time the egg is dividing up into thousands of cells in the course of the embryonic development that is beginning. This will be described in the next chapter.

If we look at the 'knotted ropes' for long enough, we see strange happenings, the first act in a grand drama, the shaping of life itself. We see how the knotted ropes, these machines of incredibly complex structure, where the individual particles, the marbles, have their exact places, capture small molecules rushing in and out of one another; these are small molecules of various kinds, each one composed of comparatively few atoms only. They are caught and fitted into the complicated molecular net of the ropes, fitted into it in such a way that we see before our eyes a new knotted rope taking shape; and finally there are along each of the 46 old ropes 46 new. When that has happened the second act of the drama, which is utterly overwhelming, begins: the wall of the domed hall breaks up, this wall which itself is composed of well arranged marbles, the pieces of the wall float in fragments all over the confused mass of structures throughout the kilometre ball. The knotted ropes twist up into spirals like a cable that is being hauled inboard; the spirals tighten up more and more, while at the same time new groups of molecules glue themselves on to the rope spirals, and finally in the drama's third act they are arranged in the centre of the kilometre ball, looking like thick sausages, each of which in reality is made of two spirals. The spiral sausages are now about 100 metres thick. In the real egg, measuring a tenth of a millimetre, they are thick enough to be seen easily under the microscope; they can be stained with certain dyes, and this sensitivity to a dye accounts for their having been given the name *chromosome*, which derives from two Greek words meaning colour and body. The 46 double spirals now lie side by side on one plane down through the kilometre ball.

If we could now from outside see right through our kilometre ball, we should be able to follow the drama further. We should see that at two places in the ball two solid bodies constructed of separate groups of molecules are being formed, one on each side of the wreaths of chromosomes; coming out from them there is an arrangement of strings of molecules, each of which on its part points towards the 46 chromosomes; some of the strings fasten on a particular spot in each of the double spirals, and now the curtain goes up for the fourth act.

Suddenly the double spirals are split lengthwise in such a way that the one set of 46 spirals slides along the molecule strings at one side of the egg, and the other set of 46 at the other side. As if cut by an invisible giant cheese-cutter, the kilometre ball is now divided into two halves with a section at right angles to the direction of the chromosome movement; in each half there are 46 chromosomes, and the egg is now divided into two cells. With this the fourth act of the drama closes, leading on to the fifth and last act.

In each of the two cells the nucleus membrane is reformed, the spirals of the chromosomes develop, losing many of the molecules that were stuck to them, and soon they make their appearance as the metre-thick knotted ropes we began with. About one to two hours later each of the two hemispheres takes up the same game, each of the four a little later again the same; and so on until our kilometre ball has divided into balls of only 100 to 500 metres in diameter. This whole process is called the egg cleavage, and it is an essential prerequisite for the initiation of embryo development; the process involved in this development is, of course, the formation of the microscopic patterns of the organs, each from its own kind of cell. Later on these cells multiply, when nourishment and other essential material is supplied to them from the mother; they divide up when they have doubled their size, grow, divide again, until the growth of the human being has been completed. The division of the cells proceeds on exactly the same system as the egg cleavage.

During all this time we have noticed that our very long and complex knotted ropes are retained; these, doubling themselves without change, are thus unaltered in form and function, handed on to all future generations of cells in the body, and also to the future egg cells and sperm cells that can fuse and then grow into the next generation of mankind. The chromosomes are therefore the firmest and most unalterable thing in all living matter; the chromosomes with their genes represent the *tradition* that is carried on from generation to generation. They represent the genotype.

If we have used our imagination and viewed the human egg, which is barely visible, as if it were a kilometre ball with its billions of atoms fitted together to a great extent in ingenious patterns, then we may have some slight idea of what an overwhelmingly complex arrangement the chemical machinery of life presents. But it did not come into existence all at once, as we know; it had two thousand million years in which to develop. That, however, is another story.

And if in imagination we have followed the main features of the life of the egg, which we have tried to render intelligible with our giant model, one fundamental fact becomes clear to us, and this is a subject we must now take up.

We let the hurricane rage through the billions of atoms of the kilometre ball, bound together into ingenious molecules. But does it not matter at what moment the egg is struck? Is it all the same whether it is struck when following its everyday course, or during one of the acts of the division drama?

Let us use for illustration the picture of a great army. The army is deployed. Its various tactical units are in position. The only movements are the constant supply and distribution of food and ammunition together with the delivery of innumerable messages. Radio, telegraph, and telephone communications are in order, everything proceeds according to plan. A direct hit on the headquarters may be fatal, but otherwise only a drum-fire spread over the whole army position could disorganize it.

It is a very different matter when the moving fight is in full swing. For now the army is vulnerable in a different way. A direct hit on the headquarters is, now as earlier, a crushing blow. But a direct hit on certain specially important units of the army may also be fatal for the manoeuvres of the whole army. A single detachment has perhaps been given so important a task to carry out—building a bridge or blowing up a piece of road, for instance—that all the plans of headquarters are overthrown if the detachment concerned is put out of action; it may result in catastrophe for the coordination of the tactical movements and objectives of all the other army units.

If we transfer this picture to the egg with its countless 'tactical units', the many complex pieces of molecular machinery, and with the reproductive chromosomes of the nucleus as headquarters, we can easily see that a not very powerful ray bombardment has far more chances of hitting a vital target when the egg is in the first and second acts of the division drama, when the deployment begins and the 'tactical units' disperse. At this juncture comparatively few radiation effects are needed to put the complicated machinery out of action. And we have actual experience to prove that this is the period of the cell's life history which is most sensitive to radiation. Cells at 'rest' can often tolerate many hundreds of *r*, some cells even many thousands, on the other hand quite a few *r* can wreck the further life of the cell if it is hit during these first acts of the drama of division.

We saw earlier that the direct hit on the headquarters of the cell or the egg, the nucleus, was destructive to the whole cell; but during the first phases of cell-division the further fate of the cell may also have been sealed, even if it is not the actual headquarters that are hit; if only one of the other areas, some of the molecular machinery essential for the chromosome movements, is destroyed, the whole mechanism comes to a standstill.

How little is needed? That is hard to say, because we do not know exactly what happens when we send lower radiated energy through the cell. Some of the energy goes through without causing any mischief beyond that of detaching a few electrons here and there; and in most cases this can be put right. It is possible, however, that only a single change of the electric charge of a single atom brought about by a single energy quantum, a photon, is enough to cause one molecule to which the atom is attached to behave so very differently, in a chemical sense, from before that the chemical change affects other molecules in a wrong way; the latter will then again behave differently, and so on in a kind of chemical chain action. This may lead to the result, at all events theoretically, that the whole mechanism of life is put out of gear, coordination fails, and the cell perhaps dies. Still that, no doubt, is among the very rare exceptions. It is more reasonable to suppose that even a low radiated energy, which in the light of experience has proved sufficient to kill the cell or cause disease in it, has destroyed the molecule machinery in so many places that as a result the whole structure is deranged, perhaps by degrees utterly destroyed.

One example. Cancer cells divide frequently and swiftly if cancerous tissue is in course of development. There are, therefore, a relatively large number of cells taking part in the first and second acts of the division drama. Accordingly cancerous tissue is more vulnerable to the rays than most other types of tissue, with the exception of the egg and the embryo cells during division, and certain other tissues, which we shall hear about later. By degrees the radiologists have been able to work out radiation amounts which just kill the cancer cells but only to a slight extent injure other tissue. That may be done in several ways. Depth treatments, in which the rays have to pass through thick layers of healthy tissue before they reach a cancerous tumour in an internal organ, may be carried out in such a way, for instance, that the rays are directed through the body down to the cancerous tissue, while the source of radiation is passed in a circular motion outside the surface of the body, so that the rays, like spokes in a wheel, all the time strike the centre, the cancerous tissue. This arrangement ensures that the cancerous tissue at all times receives the full force of the radiated energy, while constantly varying portions of the healthy tissue are exposed to the passage of the radiation; the healthy tissue in this way receives only a fraction of the amount of energy supplied to the cancerous tissue.

CHAPTER 3

Mutations

NOW we return to our picture of the army at the start of movements by units in the battle just beginning. A rather feeble shelling by the enemy may result in adoption by one of the units of a different movement from that planned; this may involve a slight re-grouping by the neighbouring units also, and the original plan for the course of the battle may have to be modified to a certain extent. Of course that always happens in a battle. And the commander-in-chief has the task of effecting a rapid coordination in the movements of all the units, in keeping with the new situation. The more widely spread shelling by the enemy becomes, the more difficult is it to regulate the whole mass of troops and to adjust the coordination of units. The enemy shelling has caused change throughout the scheme of operation that had been drawn up, simply by forcing the line of action of a few tactical units away from the course that was planned.

This is what happens when radiation produces *mutation* in a cell.

We have already pictured the genes as complex pieces of molecular mechanism placed like knots on the chromosome ropes, which themselves are pieces of molecular mechanism complex in structure. A gene is a tactical unit that has its special task to perform, in cooperation, of course, with the many thousands of other genes. Consider for a moment what must be going on in our kilometre ball; many thousands of different chemical reactions are proceeding from just as many genes, the complex pieces of molecular mechanism; out in the cells all the chemical processes, set in motion and guided, fit into one another's activities, always in a meticulously organized way; try to picture that by means of our illustration, an organized game of those billions of atoms, those billions of small various coloured marbles.

Let us now imagine that we could stick a long wire into our kilometre ball; we should give a push to many balls on the way, perhaps also bring about less material disturbances here and there; but let us imagine that we drive the wire farther in, until it reaches one of the gene knots; with a well-directed thrust we could knock the shell off one of the most important marbles, i.e. we could remove its electron. If this marble happens to be on a critical spot in the chemical machinery, the altered electrical charge might entail the initiation of a new chemical process; the entire gene mechanism would then behave differently, introduce other chemical processes, and thereby force the whole metabolism of the cell into a new equilibrium in chemical processes. A change of this type is a mutation, a true mutation or point mutation.

That the facts are such was proved through a series of ingenious experiments with X-ray and radium radiation H. J. Muller. As we have learnt, the irradiated sex cells are most sensitive in the first and second acts of the division drama. That means that the rays, or in our model the wire, strike one piece of gene mechanism in one of the two chromosomes (knotted ropes) that have just been formed. The uninjured gene is there still, carrying out its usual work, and this often causes the action of the altered gene, the *mutated* gene, to be held in check. The chemical action of the latter is said to be *recessive;* it does not become manifest but it is passed on from generation to generation.

If a mutation occurs within a cell in an embryo that is in the course of development, all the cells that originate from this cell in the embryo will contain the mutated gene, and its effects can sometimes be seen in the fully developed body; frequently, however, the new chemical machinery that has sprung up in such an embryo cell will have the effect that the descendants of that cell cannot adapt themselves to the chemical machinery of the rest of the body, and then perhaps the whole embryo will perish. It is for this reason that irradiation of embryos is so dangerous, and we are to hear about that later.

If the irradiation happens to the particular cells from which the sex cells are derived the mutation is transmitted to the individuals derived from them, whether they are egg cells or sperm cells. It is all the same for heredity whether the mutation has occurred in the nascent egg cell or in the nascent sperm cell; the new individual receives the mutated gene, but the latter may be recessive because its action is held in check by the action of the normal gene, which is therefore said to be *dominant*. So far nothing will have happened to the new individual that develops from the fertilized egg. But when once this new individual reaches maturity and develops the sex cells, half of these will contain the mutated gene. And if it should come about that such a sex cell one day meets another sex cell with the same mutation, then the mischief is done, for now there is nothing to check the chemical effects of the mutated gene. It depends in detail on the nature of the new chemical processes whether the whole collective game of gene processes can be adapted to the new situation; if this can be done, an entirely new type, a new *variety* of the species, will have arisen. We are familiar with many hundreds of mutations in mankind which cause disease or deformities. In another chapter we shall hear how the genes pass from one human being to another and are transmitted from generation to generation.

There is one more thing we must realize: mutations, chemical changes of genes with effects resulting from them, do now and then appear 'of their own accord'. The origin of these 'spontaneous' mutations is unknown. Some of them are probably due to cosmic radiation and some to other forms of accidental radiation. The majority are certainly the result of chemical action, but how this comes about is not known. We only know that we can cause mutations artificially by means of various chemicals, e.g. mustard gas, formalin, peroxide of hydrogen, or other substances rich in energy. It is specially worthy of note that some substances that produce cancer can also produce mutations.

We so often hear of cosmic radiation and of natural radio-activity also. Both of them occur in practically every part of the world, but with very varying intensity. It has become evident, too, that each one of us contains a small amount of radio-active potassium: potassium is a metal that in combination with carbon and oxygen, for example, makes up a portion of the salts we have in our body; a tiny portion of the natural potassium in our body is radio-active.

Obviously it was extremely important to be able to measure how much radiation, natural radiation, reaches human beings in various places in the world. The sum total of all this radiation has been termed 'background radiation'. In England background radiation reaching people is given as approximately three-thousandths of an *r* per week, but in other countries, e.g. in Sweden, the proportion is considerably higher; this is undoubtedly due to the existence of relatively large amounts of radium and uranium in the Swedish mountains. In many places, however, for instance in Germany, there is also radium in the drinking water; this radium comes ultimately from the weathering surface of the mountains. For that matter, in Denmark radium has been detected in water in various places, the so-called radio springs. The radium in these originates in the weathering of the rocks dragged down by ice from the Scandinavian peninsula and Finland during the ice age. The extent of the background radiation seldom exceeds three-hundredths of an *r* per week.

So small a dose of radiation is regarded as insignificant by comparison with the radiation that comes from X-ray apparatus and radium preparations of various kinds, as well, of course, as the atom-splitting machines that we are now going to use. But it is probable that, as already mentioned, this background radiation is responsible for some of the mutations that the genes in the sex cells of living beings have undergone during the whole time that life has existed on earth.

Mutations of another kind are found in the breaking up of the chromosomes. They can be produced both by radiation and by chemical effects. When cells have been exposed to radiation or to mustard gas or other chemicals it can be seen through the microscope that one or more chromosomes have snapped, sometimes in several places. When such a cell divides, confusion arises in the distribution of chromosomes to the daughter cells; only if one of the cells has obtained almost all the chromosomes can this cell survive, but the other must perish because it lacks too many of the tactical units, genes, which are necessary for the cell's normal life. In most cases, however, both cells suffer from a lack of genes and both perish. The cells of animals are more vulnerable to chromosome fracture than the cells of plants. If the cells that have had their chromosomes broken are sex cells, the embryo that arises from the fertilization will not be able to survive. In a similar way sterility also can result.

Using imagination aided by a giant model, the kilometre ball, we have formed for ourselves a faint and imperfect picture of what goes on in living matter, and of how radiated energy can alter the chemical processes in it. In the remaining chapters we can therefore with a good conscience be content to talk of the cell, the chromosomes, and the genes, etc. without resorting to our model. Yet it may perhaps be helpful to keep the kilometre ball in mind.

CHAPTER 4

The Visible Effect of Radiation on the Body

FOR the last ten years we have been oppressed by the fear of war with atomic weapons, but now a certain optimism is beginning to spread. There is a growing impression that all responsible statesmen have at last fully realized that an atomic war would not be war as it was formerly known, with its possibilities of victory and defeat—an impression that they have realized it would mean the ruin of our civilization if an atomic war were let loose. Neither victory nor defeat, but annihilation for both sides, would be the consequence. Let us take the path of optimism and accordingly refrain from any mention of what would befall mankind in an atomic war.

What risk is there for the individual human being in the atomic age during peacetime? First of all, in reassurance, it must be stated that the risk to life and health is very slight if we observe properly the precautions agreed on by those who are most expert in this field—physicists, biologists, doctors. At the great atomic station at Harwell the cases of injury to people as a result of radiation have been infinitesimal in number. The same thing is true of the far bigger Tennessee installation and of those in the U.S.S.R. Earlier experiences, gained through tragic sacrifices in the cause of science and medicine, have taught us how little radiation it takes to do harm to the human organism.

Broadly speaking, the maximum radiated energy that can safely be borne for any length of time is 0.3 *r* per week; it is extremely rare for this dosage to be reached in the atomic stations themselves or in the laboratories, and then only through carelessness. Wherever there is any work with radiation, for instance in hospitals, the weekly dosage is kept much lower, e.g. in Sweden, at 0.1 *r* (1952). We must, however, anticipate that the use of atomic power in everyday life may come to entail such great demands on safety precautions that the economic burdens involved will offer a temptation to slacken those demands. There have been feelers in this direction from those concerned with the technical application of physics. Perhaps the greatest danger will be that of the scamping or neglect by many individuals in large concerns of those strict regulations. This has already occurred, just as many people at ordinary places of work grow so practised in a routine that they no longer trouble to apply the prescribed safety measures. There are always, of course, some rules that will be evident. In the atomic installations people are given protection in many ways. One of them is that every person working in the plant carries a little piece of photographic light-protected film, like the small X-ray film which a dentist puts in the mouth when he is taking an X-ray photograph of the root of a tooth. The film is developed every week, and if there has been any blackening of the film it can be seen at once from the degree of blackening whether the person has been exposed to greater radiation than the maximum permitted.

A far more serious danger than that of operating atomic machinery is that arising from radio-active fall-out. We have heard that all radiation is gradually checked by the substance it strikes, because its atoms react with the energy that forms the radiation. The radio-active fall-out from the atomic installations can therefore be screened off in various ways: by enclosure in very thick-walled concrete containers;

by being left to settle in dredging plant; by being dropped deep down in derelict mines, and so on. But the problem will increase in difficulty with the number and size of the atomic power stations. Many experts think, however, that quite safe methods of rendering the fall-out harmless are now being discovered. Meanwhile it is essential that all should be aware of the danger and join in the demand for exercise of the strictest supervision. For if radio-active fall-out escapes, living creatures are infected, first microscopic organisms, then green plants, after that animals, and finally human beings. Probably there will never be any risk of immediate demonstrable physical injuries, but there might well be a risk of abnormal embryonic development and of insidious cancer formation, and particularly of a heightened mutation rate.

What might be the result of exposure to excessively intense radiation?

Here a distinction must be drawn between the effect of a single large dose and that of smaller doses given over a longer period; moreover the effect varies according to how large a part of the surface of the body is chiefly irradiated, and of what organs; the symptoms of irradiation appear by degrees, never immediately. After a large dose all over the body there may be flushing of the skin; necrosis of the cells with inflammation in consequence; many changes in the composition of the blood, which manifest themselves in the oozing out of the blood through the thinnest arterial walls and in poor coagulation so that haemorrhages occur; anaemias of various types also occur; severe injuries in the intestinal canal and much besides may result. A single dose of 1,000 *r* all over the body may be fatal, whereas the same dose divided up into small portions over a longer period may be without any particular effect. This tends to show that the cells that were hit, or their descendants, can in time repair the damage before the next dose comes.

All this, however, is such comparatively common knowledge that the man in the street need not give a thought to that risk. On the other hand there is a different and more insidious danger, namely the power of radiation to produce cancer. It is indeed curious that these same rays that cure cancer by killing the cancer cells can transform healthy cells into cancer cells.

In a report issued in 1939, the statement is made that 53 per cent of all the deaths among active mine-workers in Joachimstal, where there is radio-active uranium, were due to cancer, 90 per cent of this being lung cancer. It is hardly to be doubted that radiation has its own large share in this tragedy. The advantage to be gained from luminous watch and clock hands was paid for, among other things, by 41 human lives in a mere 20 years. But that was before the facts were known. In the New Jersey watch and clock factories the people who painted the hands with the substance containing radium and mesothorium were in the habit of licking their brushes to give a good finish to their work. Four to six years later many of these persons died of bone cancer or leukaemia. American statistics have indicated that the number of leukaemia cases of the kind that are due to cancer-like disease in the blood-making organs (especially the bone marrow) was ten times higher among radiologists than among other doctors. Truly we owe a debt of gratitude to those people who to cure others have risked their own lives.

The treacherous thing about the cancer that is caused by radiation is that the visible onset will perhaps not occur until many years after the irradiation has happened. This is because the various organs and tissues react differently to radiation. There is relatively swift reaction from organs with active cell-division, e.g. bone marrow and lymphatic glands, which are all the time producing blood corpuscles, and the epidermis cells, which must constantly make good this loss of dried-up cells from the surface of the body, and so on. It looks, therefore, as if there is some connection between the speed of division in cells and the time it takes for cancer to develop to the point at which it can be recognized.

We still know very little indeed of the underlying reason for the fact that healthy cells can be transformed by radiation into cancer cells. Many people are of the opinion that mutations that radiation can produce in the body cells, the somatic mutations, may be of such a kind that these cells are no longer under the control of the substances in the body that otherwise prevent normal cells from unlimited multiplication; they have seceded, as it were, from the fellowship of the other cells of the body, and henceforth appear as parasites and thieves in the cell community. The fact that radiation has its greatest effect in the primary stages of cell-division is quite in keeping with the fact that cancer produced by radiation occurs chiefly in organs and tissues with a comparatively large number of cells in process of division. This connection is confirmed by another observation, that it is relatively easy to produce cancer in sores and other lesions that are healing up, for in such places there is also active cell-division.

Certain observations tend to show that the damage from small doses of radiation received over a longer period can so accumulate that the tissue must ultimately give way to the chemical conversions brought about, and do so in such a way that the cells become cancer cells, 'malignant', as we express it. This has happened to the radiologists mentioned above and this is what we must fear generally in the atomic age, if we do not take steps for very effective protection. But it will be many years before proper statistics can be drawn up on this point, because the danger will only grow in step with the development of atomic energy and because the latent period is so long. By the latent period is meant the time that elapses between the radiation action and the visible development of the malignant tumours. But the cancer problem is gaining a new aspect, the development of which we must follow carefully. We must realize that it will be difficult to decide whether the cancer formation is due to radiation; for there are many other causes for the increase in cancer diseases, among other things misuse of tobacco. A report of 1952 states that 15 to 16 per cent of all deaths in England and Wales are due to cancer, and this is twenty times higher than the percentage for fatal road accidents. Such statistics must be followed up carefully in areas where the population is specially exposed to the new atomic radiation.

CHAPTER 5

Radiation and Sterility

WHEN the sex cells are formed, characteristic and complicated movements of chromosomes are observed, as a result of which the egg and the spermatozoon contain 23 chromosomes each. This is necessary so that the fertilized egg may ultimately contain 46 chromosomes: the number found in normal human cells. It has been seen that the many different stages to be gone through before the sex cells have been completely formed vary in their sensitivity to radiation effects. The most sensitive stages are the first, the so-called egg parent stages and sperm parent stages. Mature eggs are being formed continually in the ovaries, and mature spermatozoa develop continually in the testes so that 'parent stages' are present in the sex glands in human beings during the fertile period, beginning about the age of 13 to 14 years, and lasting until between 40 and 50 in women and 60 and 80 in men. A powerful radiation can therefore induce sterility in both men and women. With mice and rats a dose of about 100 *r* is enough to cause complete sterility owing to the breaking up of the chromosomes, so that the normal sex cell formation from the irradiated parent stage cannot be effected. Accordingly no mature sex cells are produced.

In connection with the subject of the next chapter it is worth while, incidentally, to emphasize at this point that sterility owing to radiation may occur even in the embryo. When pregnant mice were irradiated, most of the young mice born proved to be sterile when they became sexually mature. This is due to the fact that the sex organs are established quite early in the life of the embryo; a radiation effect can then check the cell division in these glands, so that they are put out of action.

With human beings an irradiation of the ovaries with 70 *r* may cause temporary sterility in women, and permanent sterility can be produced by about 300 *r*. Conditions vary, however, with the individual.

Whereas many organs will tolerate repeated irradiation with small doses, both ovaries and testes suffer permanent harmful effects from this method of irradiation, sterility coming on gradually; radiation is here said to have a cumulative effect. In the case of animals it has been demonstrated that doses as small as 9 *r* daily will gradually produce complete sterility of the testes, even smaller daily doses may cause sterility in the ovaries of animals.

It is a generally known fact that X-ray irradiation is often used to sterilize women who suffer from certain diseases in connection with the sex hormones. This, however, is always a risky matter, because these hormones influence many processes in the body, even psychological processes depending on the hormones. No doubt it is less common knowledge that in some places the temporary sterilization of men by X-ray irradiation of the testes has been practised, and this for a motive which is utterly unjustifiable, namely to prevent fertilization after sexual intercourse. Such tactics also involve numerous mutations in the testis cells that will one day become sperm parent cells and spermatozoa. Even if the individual is completely sterile during the few weeks that it takes for the irradiated sperm parent cells to develop into spermatozoa, he will partially recover his fertility and will later be capable of causing injurious mutations to be transmitted to the next generation, whence they can go on spreading to new generations, a problem I shall mention in Chapter 8.

Knowing as we do from experiments on animals that small doses of a few *r* can *gradually* induce sterility, and bearing in mind how very imperfect is the knowledge available to us at the moment concerning the problem of sterility in general, we must see the need for the utmost caution as to unintentional irradiations of the sex glands. This problem must for that reason also be closely watched in the atomic age.

But sterility may come about in another way too, in the suspension of embryo development at some time or other. Both this and the malformations that may occur during embryonic development as a result of irradiation will be the subject of discussion in the next chapter.

CHAPTER 6

Radiation and Embryonic Development

EVEN the embryo deep down in the uterus can be reached by radiation. This has been realized for many years by medical men, and accordingly they always try to screen the embryo if the mother is to have X-ray treatment. In the infancy of radiation treatment this danger was not realized, and many examples of abortions resulting from irradiation have been described in the literature of medical science. During the past fifty years comprehensive research on animals has been going on, to find out what the effects of radiation are on embryonic development. And in these investigations it has been established that even relatively weak radiation may cause malformations or sterility. For an understanding of this some account of embryonic development is necessary.

In the course of nine months a small egg cell measuring a tenth of a millimetre is to develop into a mature embryo of 6 to 8 lb. So swift is this growth that it proceeds faster than that of even the most immense cancerous induration. During embryonic development there is an enormous production of cells, and this means that at any particular time an enormous number of cell divisions will occur. Now, we have heard that certain stages in cell-division are particularly sensitive to radiation, and it is therefore not surprising that the embryo itself during its growth is also very sensitive to radiation. All the stages of embryonic development are not, however, equally sensitive.

Embryonic development can be divided into four stages. The first stage comprises the cleavage of the egg into many thousands of cells before it becomes attached, as a small growth, to the wall of the uterus; this stage lasts about ten days. The next stage goes on from this tenth day until the end of the third month. It is a period during which the most important organs are being formed. In the fourth to the seventh month, the third stage, the finer details of these organs develop, and lastly, in the fourth stage, from the seventh to the ninth month, a general growth and maturing of the embryo takes place. Experiments have proved that the first two stages are the most sensitive to radiation. Even so slight a dose as 25 *r* kills many of the very young embryos before they become embedded in the wall of the uterus. These results have been obtained by means of experiments on animals. Now the process called radioscopy is a comparatively mild irradiation, and it is of course often employed in examinations of the woman's abdomen, where the presence of something abnormal may be suspected. In many of the radioscopy appliances the strength of the radiation is such that approximately 30 *r* are emitted per minute. If a radioscopy lasts 5 minutes, for example, the dose may very well go up to almost 100 or perhaps even over 100 *r*. It is obvious that if the doctor knows that the woman to be examined is pregnant he will take every precaution against injuring the embryo. In many cases, however, there is the risk that the woman does not yet know whether she is pregnant, if no pregnancy test has been carried out. As the fertilization of the egg takes place about 14 days after the end of menstruation, an incipient pregnancy may have occurred at such a time that any radioscopy applied may take place when the embryo is a few days old, just in the extremely sensitive period. We do not yet know how resistant the human early embryo is to radiation, but if we consider the experiments on animals, we shall surely find extreme caution advisable when contemplating any irradiation of the uterus during these particular days; in any case radioscopy should take place just after the end of menstruation and at the latest 14 days after, i.e. before an egg has been released from the ovary and possibly fertilized. There is, then, a danger that too extensive a use of radioscopy may have a sterilizing effect, so that very young embryos perish. In the approaching atomic age we must realize this risk. As already mentioned, it is very unlikely that radiation doses of 25 *r* could occur where the forces of the atom are being dealt with. But all the same we ought to watch out for the risks occurring here.

The next stage of embryonic development is also extremely sensitive. When the very young fetus on the tenth or eleventh day has become attached to the wall of the uterus, a tremendous proliferation of cells takes place, serving partly to attach the embryo to the uterus wall and partly to perfect the embryo itself. The embryo at this point is only a fraction of a millimetre long, with no indication of organs, being simply a flat mass of cells. But now events move fast. Here we must consider mainly the development of the nervous system, and particularly of the brain. On the future back of the embryo two ridges of cells spring up, separated very slightly from each other; these two ridges gradually draw nearer to each other so that a deep trench is made, and shortly afterwards the upper edges of the trench become fused in such a way that a tube, as it were, is formed under the surface; this tube is the very first beginning of the future nervous system. The cells on its inside divide, and every time a cell has divided one of the cells is pushed out into the wall of the tube, which thus grows thicker. The cells that used to form the wall of the tube are then gradually converted into the various kinds of nerve cell that ultimately form the brain and spinal cord. The frequency of cell-divisions in the various regions determines the number of the particular cells that will build up the brain and spinal cord. It is genetically determined how many cells, at least approximately, are formed; in the end the human brain will be composed of something like ten thousand million cells. If, then, the brain in its first stage of construction is hit by radiation, cell-division is either entirely prevented or is retarded. The result will be fewer cells in the brain. We know practically nothing as to how powerful irradiation of human embryos must be to bring about a restriction in the number of cell-divisions, but experiments on animals tend to show that the more powerful the radiation, the poorer the brain development will be. The most serious aspect of it is that we do not know how small the doses of radiation may be that are still capable of arresting individual cell-divisions and thereby making the brain slightly less efficient than it would otherwise have been. Here is a point on which a great effort in research is imminent, as there is a possibility that even minute doses will be capable of impairing the development of the brain during these very early stages of the embryo.

We know that irradiation may cause the brain development to be very poor in the embryo. In the medical literature many descriptions occur of embryos with underdeveloped brains, for instance microcephalic ('small brain') and hydrocephalic ('water brain') embryos. There are many unsolved problems here connected with the many still unsolved problems of how the development of an embryo proceeds. In addition to the number of cell-divisions, there are many other factors that enter into the formation of a normal brain. When the embryo develops there are frequent migrations among the cells, and these cell journeys bring about contacts between new cells, with the result that they react chemically on one another. These interactions are necessary for the natural development of the various organs.

Now if radiation has the effect of reducing the travelling speed of the cells, or perhaps in some cases of accelerating it —we do not know—such cells will either not reach the particular cells with which they should normally cooperate or will come to them too early or too late and thus upset the whole process. The influence of radiation on all this is still, broadly speaking, unknown and, again, we do not know how slight a radiation can be to interfere with these cell journeys.

Other problems, too, must be solved. When the cells inside the neural tube have divided and have been pushed into the wall, there to be converted into nerve cells of various kinds, this conversion proceeds chemically, new substances being formed in the cells—substances that are necessary in order that the cells may be able to perform the tasks allotted to them. The chemical activity that goes on in such cells is of a very delicate nature, and it is quite conceivable that radiation may interfere to the detriment of these chemical reactions. Nor do we know, even here, how little radiation is necessary to produce a harmful effect.

Thus the brain during its early formation is an extremely sensitive organ. Quite different investigations, too, have established this fact. Experiments have been carried out in which pregnant rats have had an insufficiency of certain vitamins in their food, with the result that the young ones born suffer from deformities of various kinds; some of these deformities affect the brain. From this the conclusion has been drawn that the chemical processes that take place in the cells during their conversion into fully developed brain cells cannot carry out their chemical work properly unless they are supplied through the mother's blood with just those vitamins that are necessary.

Experimental embryology is becoming more and more aware of the fact that even small changes in the chemical machinery in those cells which are to develop into the various organs may have injurious results.

Ordinary human intelligence, what is inadequately termed 'normal' intelligence, is the property of brains the weight of which varies by 50 to 100 grams on either side of the normal, i.e. round about 1300 to 1400 grams. If the weight of the brain is considerably below this figure the individual is mentally defective. There is thus a dangerous border region where the level of intelligence the individual can attain may be determined partly by the relative number of cells in the brain. We must face the possibility that irradiation of the embryo may cause a somewhat inferior development of the brain, so slightly inferior that there would not even be actual deformity of the brain, but that would nevertheless render the individual concerned less intelligent than he might otherwise have been.

It must be emphasized once more that the danger from radiation is far the greatest in the early embryonic stages, which in man last from the time of fertilization up to about the end of the third month. After that time the embryo grows more resistant, and this in all probability is connected with the fact that the principal cell migrations and the earliest cell-divisions are well over. Experiments with animals have shown, in any case, that there are fewer malformations when the prospective mothers have been exposed to radiation during the fourth to seventh months of their pregnancy. Still less damage is done by radiations during the last months of embryonic development.

The effects of radiation on the development of human embryos have been demonstrated in a scientific examination of children in the Nagasaki area who were embryos when the atom bomb did its work. The report was issued jointly by a Japanese and two American scientists. Even if atom bombs will, we hope, never again be released, the report of the inquiry ought to be made public, since it, too, may take a share in creating the world opinion that can contribute towards the prevention of war.

The bomb over Nagasaki exploded on 9 August 1945. At this time 98 women were pregnant in an area of the town about one and a quarter miles in diameter directly below the point of explosion of the bomb, an area termed the hypocentre. Of these 98 embryos, 28 per cent died before the normal term. As material for comparison, a control group of women who lived two and a half to three miles from the hypocentre of the bomb was selected. To obtain figures for easier comparison, there was picked out at random an equal number of women, 1,774, who survived from the hypocentre of the bomb. Of the 1,774 controls, 113 were pregnant on 9 August 1945. Only 2.6 per cent of the embryos in this group aborted. It is thus established that the fetal mortality in the hypocentre was appallingly high. Moreover it may be taken for granted that many women were in the early stages of pregnancy without being themselves aware of it and could therefore not be recognized by the scientists making the inquiry. There can be no doubt of the fact that many of these very young embryos were killed by the radiation, and also that many of the women became sterile.

The fact that mortality among embryos was greatest in the first months of pregnancy does not in itself show whether the mortality was due to the irradiation or to the indirect effect on the embryo through the placenta or in other ways from the more or less damaged tissues and the blood of the mother. Perhaps it will be said that this in itself is a minor matter when, after all, damage is done anyhow. It is not certain however that the matter is so trivial, for injuries from irradiation may to some extent be prevented with special substances, and naturally it is important for practical treatment to know whether the body of the mother or of the embryo has been affected. Experiments with animals tend to show that it is the direct action of radiation on the embryos inside the uterus that caused the high mortality as well as the large number of malformations that occurred among the children who were actually born.

For among the children born, too, lamentable effects of irradiation were revealed. Several died in their first year, others later. Only half the children of mothers most severely affected attained the age of six. Among the surviving children, height was one inch less than the normal and their weight was four and a half pounds lower—both signs of reduced vitality. The head circumference also was up to an inch less, indicating a smaller brain. Several of the children also had diminished mental faculties; a few were still unable to talk at the age of five.

I have spoken of malformations of the brain due to the effect of radiation. But radiation also influences the formation of all the other organs. It happens, however, that the various organs in the embryo develop at slightly different periods during the course of development, and it therefore depends on the time of the irradiation which organ is hit in the sensitive phase. The doctors at first were astonished at the phenomenon that embryos injured by radiation offer such a tremendously varied picture, some embryos having some organs deformed, other embryos other organs. We are now in process of discovering, through experiments on animals, why this is the case. If the radiation strikes just at a moment when a particular organ is at the opening phase of its establishment and formation, this organ will be deformed; if the radiation strikes at another moment, when another organ is affected in its early establishment, this other organ will suffer.

I must mention further a very peculiar but also a very ominous effect of radiation on embryos. As already stated, it has been proved in many experiments that the young ones born of irradiated animals, besides showing certain deformities, also turned out to be sterile when they reach the age of puberty. It is odd indeed that, through irradiation of embryos, sterility can be brought about, showing itself only when the animal has reached maturity. The explanation is that the gonads,[1] like the other organs, have their critical stages early in the embryo life, and if the cells from where gonads descend are struck by radiation at these stages they may be wrecked in such a way that later on the sex organs cannot perform their function, even if this state expresses itself in no other way than in the non-formation of sex cells. Obviously this is also a point that must be taken into account when we consider the effect of radiation to which human beings may be exposed.

Added to all this is another possibility that may perhaps have far-reaching results. When the sex organs are established in the early embryo the so-called original sex cells are formed in them. Irradiation of these original sex cells even at this early stage may bring about mutations in the chromosomes, in such a way that the sex cells proper in the sexually mature individual produce sex cells with mutations that may be transmitted to the offspring and thus yield far-reaching damage in future generations. Here we have come to the most serious aspect of the effect of radiation—the danger of producing mutations in man in a number exceeding the frequency of mutation that otherwise occurs. This is the point I must consider in the next chapter.

[1] The gonads are the sex glands: in woman, the ovary; in man, the testis.

CHAPTER 7

Radiation and Man's Genetical Constitution

'THERE can certainly be nothing but genetic disadvantage for man in artificially raising his mutation rate, by irradiation or any other means, above that which has sufficed for his evolution up to the present.'

K. MATHER, 1952

'. . . social protection increases the danger from increased mutation rate.' C. D. DARLINGTON, 1952

'The genetic defects would consist in part of the obvious and gross ones and in part of the minor ones which tend to reduce the fitness of many apparently normal individuals. The latter effect may well be rather considerable and the more important from the point of view of the species as a whole. The total effect may well be very serious or even disastrous.'

D. G. CATCHSIDE, 1952

'There must be a call to arms in face of the danger that vagabond radiation will bring about disastrous mutations in human communities.' ØJVIND WINGE, 1955

'Science and technology have today created almost unlimited possibilities for further human progress and evolution. Unfortunately, at the same time, we have reached a stage where human mistakes can have a more disastrous effect than ever before in our history—because such mistakes may drastically change the course of man's biological evolution.' M. WESTERGAARD, 1955

THE above quotations from leading geneticists are only a small selection. More forceful pronouncements come from the man with perhaps the greatest name in genetics today, the Nobel prize-winner H. J. Muller. All these scientists have carried out research on mutations in various animals and plants, and they have found the same laws valid everywhere in the world of living things. Even if the calculation of the frequency of mutation shows differences according to the species of animal or plant, it is certain that similar qualitative laws hold good for man also. We are without accurate knowledge of the frequency of mutation in man because we cannot experiment with man, and because the generations of mankind succeeed one another at about twenty-five-year intervals. Yet even the fact that mutations occur in man in the same way as in all other living beings shows us that the same forces that can increase the frequency of mutation in animals can do so also in men. Radiation increases the frequency of mutation in animals, therefore also in men.

I mentioned earlier that each individual is exposed to background radiation, which varies from place to place but on the average may be put at a 5 thousandth part of an *r* per week. That makes a quarter *r* per year, or roughly ten *r* during the reproductive age in human beings, a little less in women, a little more in men. In addition there are mutations brought about by other agencies. The average frequency of mutation that results from all this has been responsible, in the course of the millennia, for the appearance of the human race as it is today. In the great majority of these vast periods natural selection, with the aid of the outside conditions provided by nature, has influenced the generations, favoured the beneficial mutations, held the adverse ones in check or eradicated them. All around in the sex cells throughout mankind there is an abundant quantity of recessive mutations which are revealed only to a slight extent or not at all. The same holds, of course, for all living beings. In the realm of nature these mutations are held in check by natural selection. The majority of them are harmful owing to the fact that when they become manifest in an individual this individual is somehow or other less resistant, and therefore its chances of survival and of transmitting its mutations to posterity are smaller.

But man has now conquered nature in many spheres. A fight against disease in every direction is gradually eliminating the rough selection of nature. Nature knows nothing of the concept of compassion. Many of the particular mutations which brutal nature would hold in check or eradicate are now being given opportunities of spreading; hygiene and medical skill maintain their existence, they are transmitted from generation to generation and reproduced through the sexual process. In the next chapter I shall refer to this reproduction.

What is really meant by the expression that a mutation is harmful?

A fly like the banana fly, the creature most dear to the geneticist, carries those mutations which in the dawn of life for these insects provided them with wings that allow them to conquer the air; which gave them the means of dispersing to other localities where food is in more abundant supply. But in the sex cells of many such flies there is a recessive mutation which would produce stunted wings if the normal gene for normal wing development were not present and dominant. If, however, an egg with the recessive gene is fertilized by a sperm cell that also contains the gene, then there is nothing to prevent the activity of the gene from becoming manifest, and the individual that develops from the egg will have stunted wings. But as a result its capacity to seek out food is impaired, and it will succumb in competition with the flies that have normal wings; its chances of giving birth to offspring are infinitesimal. In this way the harmful mutations are kept down. Yet the mutation is only harmful *in relation to the normal conditions* under which the banana fly lives. Experiments have shown that mutation for stunted wings under changed outward conditions may turn into an advantage. When flies with normal wing genes and some with the mutant were released on an island where it was always windy, the succeeding generations showed an even greater percentage of individuals with stunted wings, because those with wings were blown away, whereas the others could hold on.

Lice derive from other insects, which have wings; but they themselves have lost them through mutations, because wingless mutants are better adapted to a parasitic existence.

When we say that the majority of mutations are harmful, we must add: in relation to the conditions prevailing at the time.

That, however, is not the whole story.

For a great many mutations always have a harmful influence, whatever the conditions turn out to be. Some mutations actually cause the death of the individual, which may take place at any stage, from the fertilized egg until the adult life begins. Such genes are called *lethal*. Others seriously impair vitality; they are called *sub-lethal*. There are many of the latter. But even more mutations simply impair vitality in a very slight degree, so little that it can hardly be recorded. These may be the most dangerous mutations for the whole race.

When lethal mutations disappear with the individual owing to the death of the latter before the birth of any offspring, it might be thought that the mutations had gone for good. But the fact is that such mutations do now and then re-emerge in sex cells, produced by external influences on the genes, whether due to 'background radiation' or to chemical influences of a 'natural' kind. However the lethal and also the sub-lethal mutations will be severely kept down by natural selection. An example of a sub-lethal mutation is inherited haemophilia in human beings. I shall refer to this in the next chapter. But the many mutations that only slightly impair vitality can hold their ground for a tremendously long time, generation after generation, because there will always be numerical equilibrium between their emergence by mutation on the one hand and the power of natural selection on the other. Now, the more we do away with natural selection, the more such mutations will spread, the more often will they occur in double portion in the fertilized egg cell. The affected individuals and also the whole population will thus in time become less fit.

In our domestic animals we have deliberately promoted the progress and spread of certain mutations which indeed serve our human ends well, but which make these creatures unfit to live out of doors in nature's hard climate. A pure-bred Danish red milch cow would not get on well if she were let loose on the veld plateaux of Africa. Or how would a pekinese survive if he were left behind in trackless forest without human protection?

Here we have examples of mutations that are certainly harmful under natural conditions and that therefore are not permitted to show themselves where natural selection is dominant, but may flourish under the artificial conditions man provides for them.

Our knowledge of genetical conditions in man is still extremely slight. True, we are acquainted with five to six hundred mutations, which in one way or another cause diseases or deformities. But, to judge from experience gained through research on animals, there must be in existence many small mutations that weaken the whole finely balanced chemical machinery that constitutes a human being. The number of mutations of this kind has been estimated at three to five times the number of other mutations.

If the frequency of mutation is speeded up we can predict with certainty that 3 groups of mutations will be strengthened in their harmful influence on mankind.

1. Those which cause sterility (which are practically lethal);

2. Those menacing to life (sub-lethal), among them being those which cause malformations of one or more organs;

3. The deleterious mutations.

The third group will to all appearance increase relatively more than the first two, if we speed up the frequency of mutation.

How much radiation does it take to cause a perceptible rise in the frequency of mutation? This question obviously cannot yet be answered as far as man is concerned, since we have of course no experience to build on and we cannot experiment with human beings. But if, on the basis of results obtained in animal experiments, we make certain calculations, an extremely serious prospect emerges. However, it must be admitted that various scientists differ greatly from one another in their assumptions as to how much radiation it would take to double the present frequency of mutation in man. In the banana fly the figure is well known, about 40 *r* per generation; in mice it is estimated at approximately 50 *r* per generation. Some people consider that it would take 150 *r* to double man's frequency of mutation per generation (25 years), while others, among them H. J. Muller, hold the opinion that about 80 *r* would suffice; finally there are pessimists who insist that merely a few *r* would be enough.

One question that many people will certainly have had on the tip of their tongues is this: what is meant by so many *r* per generation? Does it mean that an individual is to have a certain number of *r* at one time, or is the action the same when the same number of *r* are distributed over the whole period of fertility? It was stated earlier that a certain number of *r*, as many, for example, as are needed to destroy a cancerous tumour, are more readily tolerated by living tissue when the necessary dose is distributed in the form of small doses over a certain period instead of by firing the whole cannon at one go. Is it not the same, then, with the sex cells? Are not more mutations produced in one powerful bombardment than in many small ones?

The answer is no. Numerous experiments carried out by several research scientists have established incontrovertibly that the frequency of mutation caused depends *only* on the total dose of radiation, irrespective of whether it is administered at low intensity for long periods or in smaller or larger fractions over a longer or shorter time or in a single large dose. This applies to the so-called mutations proper or point mutations. If doubling of mutation speed was effected by, for example, 50 *r* per generation in us human beings, then it does not matter whether the 50 *r* per generation of mankind is given all at once, e.g. by irradiation of a tumour near the ovary in a woman's abdomen, or an irradiation of cancer-like tissue in a man's scrotum; or whether it is applied in frequent radioscopies of the abdomen over a few years; or again if it is received continuously through the reproductive years, as for example in uranium mines where precautionary regulations have little effect.

Altogether different factors, naturally, will determine whether the mutations produced are to be transmitted to the next generation, and so on. If the person irradiated never has offspring, the mutations that have appeared are obviously quite without significance for the race, as they perish with the person. The crucial factor in the whole problem, therefore, is an assessment of the proportion in mankind on the whole of exposure to mutation-causing radiation.

Rough calculations have been made of what effect on mutation the various X-ray treatments in hospitals etc. may have for the population as a whole. There are so many unknown factors in these calculations that they can be regarded only as indicative of what we may imagine *could* happen if radiation were put into use in earnest without the requisite safety regulations.

In Sweden, where as with us radioscopy, actual X-ray treatments, and radiography are extensively applied, it has been calculated that the amount of radiation received by the sex organs up to the end of the reproductive age is only one fiftieth of an *r* per individual, if the action is thought of as distributed over the whole population instead of over perhaps 1 per cent, as it is in actuality. It may sound odd that we thus without further ado allot the radiated energy among the whole population by means of calculations, instead of concerning ourselves only with those who are actually irradiated. But this procedure is permissible, because the mutations produced by irradiation in a relatively few individuals will after the passage of many generations be distributed over the whole population. Of course it is not with individual concrete cases that we are concerned, but with the damage that may be done to the genetical heritage of the whole population.

The figure indicated for Sweden coincides approximately with that estimated as valid for the United States and Great Britain. And happily we may say that the figures are considerably below what must be regarded as the danger-line, which may perhaps be put at 1 *r* per individual per generation.

Nevertheless, even if only comparatively few individuals receive so great a dose of *r* that there are many, far too many, mutations in the sex cells of the person concerned, these mutations *may* cause great damage in the individual person or the family in the case of peoples where marriage between kinsfolk is the rule—in remote places or in small communities and on small islands, in noble families or in royal houses. I shall consider this further in the next chapter.

However that may be, one thing is certain: any radiation on human beings which exceeds, even in relatively slight measure, the present level (this being due in part to 'background radiation' and in part to the use of radiation in hospitals and clinics), raises the frequency of mutation. How much speeding up of mutation mankind can tolerate without 'degenerating', we do not know. After all, it depends also on economic conditions in the society of the future. There is the question whether it will be found possible to procure suitable and productive occupations for persons who shows signs of harmful mutations. Hans Andersen for example, delicate in health as he was, would hardly have survived in the primitive conditions of the Stone Age, but the more humane pattern of society in the nineteenth century had created conditions in which his type could provide a priceless contribution to the community.

We must always, of course, judge the value or absence of value in mutations in relation to the prevailing conditions. The more mankind develops its culture in all directions, the greater is the number of possibilities created for more new mutations to adapt themselves and contribute their share to the riches of our civilization. The question is. can the power of our civilization to open fresh possibilities of life keep step with the frequency of mutation? We cannot know anything about that. We can in any case be sure, however, that if the frequency of mutation is *materially* raised, it will be impossible in the long run for the civilized community to keep in step with it, and if this comes about in generations of the future, by degrees such a total of individual tragedies will mount up that these generations will curse us as their ancestors for not having foreseen the danger of radiation's power to create mutations.

It can be foreseen that the atomic age will provide men with a mass of materials emitting radiation, even if this is so slight that it can be regarded as without significance for the single individual. But we must take care that the use of such goods does not result in people's sex organs receiving more radiated energy than small fractions of an *r* per individual per generation.

This idea will certainly be distasteful to many inventors and technicians, and people will try to overlook the danger, even indeed to ridicule it. Let us hope it will turn out that they are justified. Until then, however, and unfortunately many generations must pass before the question is settled, it is the duty of biologists to issue warnings and to recommend the utmost caution.

We are launched on a long-term programme. Let us carry out research and make calculations while there is time.

There may still be some reason for referring to the danger involved in test explosions of hydrogen bombs. Several times, and most recently in November 1955, there was registered at many places in the world an increase of radioactivity in the air as a result of hydrogen bomb experiments. But in this connection people think mainly of the danger to life and health, not of the effect of radio-activity on increasing mutations, of which we know practically nothing. However, we must for the present regard this risk as extremely slight, amounting, for the population of the world taken as a whole, to perhaps only a thousandth part of the effects on mutation resulting from natural radioactivity. But if many hydrogen bombs are exploded in tests, undoubtedly a perceptible increase of mutations in coming generations must be anticipated.

CHAPTER 8

The Transmission of Genes

'GENTLEMEN prefer blondes'. Quite apart from the fact that it is the women, I dare say, who in actuality more often than the men choose their mates, the statement is not true unless it is meant to imply that there are so few gentlemen in this and other countries that they can have no influence on the numerical incidence of blondes and brunettes and of brown- and blue-eyed individuals. For it is actually the case that the proportion of brown-eyed to blue-eyed individuals is astonishingly constant. In Denmark there are roughly 64 people with blue eyes to 36 with brown. In more southern population groups, the proportion is 9 to 91. On the basis of observation, simple calculations may be made indicating that this state of affairs will continue as long as there is no noticeable tendency for people to prefer one or the other eye-colour in their marriage partners. Particular individuals may well show a bias in one direction or the other. A woman may say: 'I will never marry a man with brown eyes, for such are deceivers ever!' Another woman may say: 'I will never marry a man with blue eyes, the whole lot are stupid!' Both remarks (which were really made) are of course equally foolish. But they serve to show that opposing tendencies in this matter may be equally frequent, so that the proportion of blue and brown eyes remains constant. There is, however, yet another condition to be fulfilled: the blue-eyed and the brown-eyed must have even chances of holding their own under the given conditions (especially of climate). It looks as though brown eyes in the stronger sun of more southern lands are at a slight advantage; but as soon as equilibrium has set in between this small advantage and the frequency of mutation to the gene for blue eyes, then too there will be equilibrium in the proportion between persons with blue and those with brown eyes. This probably happened long ago in southern Europe after the Cimbrians, Teutons, and others brought to the population some genes for blue eyes. We may call the gene which produces the brown eye-colour *B* and the gene producing blue eyes *b*; *b* is recessive in face of *B*, but if *b*'s frequency is much greater than *B*'s (in Denmark 80 *b* to 20 *B*), the number of individuals with *b* in their cells is more frequent in spite of the recessive tendency of the gene. In southern Europe the proportion is about 30 *b* to 70 *B*. But even in population groups where there are, for example, only 1 per cent of the blue-eyed, the recessive gene occurs in the cells of many of the brown-eyed, but does not show itself very much, because it is recessive.

A great many other genes behave in the same way as the 'blue-' and 'brown-eye' pair of genes. And that means that in every population group there exist numbers of recessive genes that are not noticed, because they do not find visible expression in the majority of individuals who carry the gene concealed within them. In fact many genes of a harmful nature are spread in the population; but since happily they are of rare kinds, it is even rarer for them to meet another sex cell carrying the same recessive and harmful gene. The chances that a certain number of rarer recessive genes will meet when an egg cell is fertilized is smaller in larger populations where marriage occurs unhindered by social distinctions dependent on differences in occupation, religious traditions, and the like; or by boundaries like the English Channel or other geographical frontiers, for example parish boundaries. It is therefore an advantage for the vitality of the population, if we take this in the widest sense of the term, that marriage can occur without hindrance from all these considerations. Endogamy through many generations in small population groups, e.g. on small islands or in princely and noble families, always causes the recessive genes present, which as we know are generally of a harmful kind, to become manifest in the offspring. Mankind must have an interest in the circumstance that the increasing traffic between countries and nations leads to ever more frequent marriages between people living at a distance from each other. Half-caste has been a term of abuse in many places, especially among Europeans, and it is true that many half-caste persons look miserable and perhaps behave suspiciously. This is not, however, usually due to their hereditary characteristics, as has been alleged, but to the fact that they are often regarded as riff-raff, and therefore have to get along as best they can; if a half-caste is unreliable, this is not the fault of his genotype but of adverse circumstances whose influence on the genotype conduces to an unhappy type of individual. And those unfortunate circumstances have been produced by unsympathetic people. The more the genes disperse, the better on the whole. We can carry out a little experiment. Let us place 10 white balls in a bag: they represent sex cells that have no harmful mutations. Now let us put 2 red balls in the bag with the white ones, and these red balls stand for sex cells with harmful characteristics. Then let us shake the bag well and with our eyes shut let us take up 2 balls corresponding to 2 sex cells representing 1 egg and 1 spermatozoon. The 2 balls represent, then, a fertilization, a new individual. Now let us make the same experiment with 100 white balls and 2 red. It is obvious that in the second instance our chance of getting a pair of red balls is much reduced; so the experiment shows that a certain number of harmful mutations spread out over a large population group have fewer chances of showing themselves in double portion in new individuals.

Accordingly the numbers of individuals suffering from recessive and harmful genes can be kept down by free intermarriage among all peoples on this earth. It is of the greatest importance for the welfare of future generations that this should be understood. If the frequency of mutation is raised by radiation, i.e. if still greater numbers of recessive and harmful genes appear, it will be still more harmful to confine intermarriage to small groups. It is the journeyings of the genes that determine the future condition of humanity. But obviously these calculations hold good only if natural selection continues to operate.

Among the Jews of old it was known that haemophilia was passed on through mothers who were not bleeders themselves, the disease being practically restricted to cases among the male sex. It is, as we put it, sex-linked. If a mother had borne a boy who in the ritual of circumcision turned out to be a bleeder, the next son of this mother, or at any rate the third boy, was absolved from the otherwise strict ritual. Here, then, man interfered deliberately with the course of nature. Later, in some European royal families, every possible precaution was taken to prevent haemorrhages in boys with haemophilia—this, too, a deliberate interference with the course of nature. In all such cases everything is done so that the bleeders shall not die, but live to be of marriageable age, and thereby give the harmful gene a chance to continue its life in future generations. In primitive communities this would not happen, the boys would bleed to death; the gene would perish before the occasion arose for it to be passed on through a woman to a new generation. But as we saw in a previous context, mutations do now and then arise anew, spontaneously, so to speak.

This is an example of how we human beings by virtue of our intelligence and civilization fool nature. Natural selection, which without interference from man gradually, as it were, eradicates harmful genes, is a factor that has a strong influence on the frequency and transmission of the genes. It is through the operation of this process that life is perpetuated; but it holds good only for large populations, that is to say communities of individuals among whom mating occurs randomly. In small populations, where the number of harmful genes may be large in relation to the number of individuals, it can easily happen that the population dies out because far too many individuals receive the harmful recessive mutations in double portion and are therefore affected by the characteristics that are harmful under the given conditions.

We human beings in this way counteract natural selection. And that is just as well, so long as the frequency of mutation is no greater than it is now. For individuals who carry harmful genes like that which determines haemophilia may also be the bearers of many genes that have a high value for the community. People with certain hereditary deformities, e.g. of the limbs, may be in possession of gene-determined hereditary characteristics, intelligence, for example, which confer such positive advantage to the community that everything must be done to lighten their lives. And in addition there is the ethical aspect, which at the present time overshadows all else: human beings must help one another in every way, for otherwise we shall have no humanity.

With the atomic age enormous problems emerge in relation to the frequency of harmful recessive genes. Many geneticists are already profoundly troubled, as has been indicated. A higher incidence of mental disorder; an increasing quota of 'bad risks', as the insurance companies put it, implying lowered vitality even if the life-span is not reduced; a greater suicide-rate—these and other phenomena may all arise from the altered conditions with which our strained technical age confronts us. Wars and economic hardship also play their part. But to some extent these conditions are due to our interference with natural selection. Unless we safeguard ourselves to the utmost against radiation's power to produce mutations, the harmful recessive genes may grow more varied and furthermore each variety of gene may spread more rapidly among mankind. This, as I pointed out earlier in the chapter in emphasizing the expediency of the utmost possible freedom in the choice of marriage partners, may come to mean a deterioration in the heredity of the whole human species. Many pessimistic geneticists believe, on statistical grounds, that they can foresee a progressive degeneration of mankind, perhaps perceptible only after the passage of many generations. It is certain, however, that if we feel responsibility for the future of the race, we must concentrate vigorously on investigating the movements of harmful recessive mutations in mankind.

The problem concerning the frequency of mutation *may* in the future be so overwhelming that our established ethical principles will have to be revised, purely on economic grounds, because a time might come when there would be too few fit people to take care of the less fit. Either we must keep down the frequency of mutation by avoiding effects of radiation; or we must find means of producing favourable mutations; or we must enthrone once more nature's own method of maintaining the human species—natural selection—just as it has operated among certain primitive peoples. The third course would involve a complete break with all ethical standards concerning our fellow men; the second we are unable to achieve at present. There remains only the first, which we *can* carry out, if we want to have some control over the distribution of genes.

CHAPTER 9

Radiation and Deleterious Mutations

IN the entertaining and thought-provoking novel *The Mouse that Roared* (*Musen, der brølede*) by Wibberley, a nuclear physicist shows the politicians an utterly freakish creature like a nightmare apparition. He induces them to believe that mad creations of such a kind—looking as if they had been conceived in a delirious brain—would result if a super-atomic bomb were used. And the politicians depart in a shaken and reflective mood. The monster was in reality an artificial product of several animals tied together in a fantastic and uncanny fashion; after the politicians had gone, the animals were let loose and romped happily around.

I have been told that a widely held popular view assumes that atomic radiation may cause such mutations that humanity of the future will consist of or at any rate contain numbers of fantastically grotesque individuals.

An atomic war is frightful enough in its immediate effects, and the consequences of the peaceful uses of atomic power without the application of the strictest protective measures against escaping radiation are serious enough in themselves; bogies invented to produce belief in a future human race of deformed beings are both superfluous and harmful, and they have no basis in fact. The truth is that a future with these sorts of crazy mutation is an impossibility.

I have stated that the genes are large molecules of a very definite chemical construction, in which the atoms are attached to one another in a precise pattern, in the same way as the separate parts in a very complex piece of machinery. By virtue of this pattern the chemical activity of a particular gene is always of a very specific kind. The specific chemical activity proceeding from a particular gene must later coordinate with corresponding chemical activities proceeding from all the other thousands of genes that have been placed in the chromosomes of the fertilized egg. It is by virtue of this interplay that the substances in the egg cell and the substances supplied through the placenta to the growing embryo are organized and built into the new individual in such a way that just one individual being with its particular characteristic qualities emerges.

It is easy to understand that all this prodigious, yet finely balanced, system will tolerate only very small disturbances without breaking down. Changes that are too drastic have the result that the chemical gearing of the genes into one another's spheres of operation does break down.

If owing to radiation many deleterious mutations occur in the sex cells or in the elementary stage of the embryo, the chemical machinery of the genes cannot be put into gear, and the result will be that the very young embryo dies. This is what I referred to earlier as a form of sterility. If the mutations have not been so numerous that the embryo dies very early, it may be supposed that they are, all the same, numerous enough to bring the development of the various organs into a wrong balance, and thus a malformed infant is born. Although radiation may produce such malformed infants, there is not the slightest possibility that they could develop from this stage to childhood much less to maturity, and thereby impart to humanity a tendency towards the completely grotesque.

To all this may be added the fundamental fact that many mutations are recessive, which means that they do not become manifest in the first generation. Mutations that might possibly produce grotesque forms must therefore, to achieve visible expression, be present in a double portion, which means that a sex cell carrying the recessive mutations must meet a sex cell that has the same recessive mutations. A grotesquely deformed being would be the result of many mutations, and it would be extremely improbable on statistical grounds that the two sex cells that met would each carry precisely the same 10 recessive mutations, assuming that a mutation of a grotesque kind must have precisely 10 mutations in order to declare itself; but it may well be the case that more mutations would be needed, and then the likelihood of a meeting between two such sex cells with the same mutations would be even more remote. Accordingly it can only, in fact, be a question of somatic mutations, those which occur in the cells of the body, and then in the very early embryo cells. It is conceivable that such somatic mutations might express themselves in severe malformations of various organs, but this, as I said before, will lead to the death of the young embryo at some stage or other and its miscarriage; moreover, such mutations are not inherited.

CHAPTER 10

Isotopes

EVERY atom has an identical number of positive and negative charges, i.e. protons and electrons. Usually there is in the nucleus an additional fixed number of neutrons, which carry no electrical charge. But, as was described in Chapter 1, some of these neutrons may under certain conditions be added to the nucleus or removed from it. In this case we speak of isotopes. Zinc, for example, occurs in the form of 10 different isotopes, according to the number of neutrons in the atomic nuclei. As it is only the electrical conditions in the atom that determine its chemical properties—the power to combine with other atoms into molecules—all the isotopes of a particular element react chemically in the same way.

In ordinary water the hydrogen that is chemically combined with oxygen is of two kinds: 'true' hydrogen and the isotope deuterium (from the Greek *deuteros*, meaning second). This isotope atom has one neutron and one proton, and is therefore heavier; that is why a water molecule formed by the combination of two deuterium atoms with one oxygen atom is heavier than ordinary water molecules ('heavy water'). This type of molecule occurs in all water in very small quantities, 0.015 per cent. By means of an electric current the lighter atoms can be disengaged so that heavy water is left. Only countries such as Norway with cheap electricity can afford to produce it.

Heavy hydrogen is a stable isotope, and is only with great difficulty broken up. But isotopes of many other elements easily break up, one atom now and then being transformed into the stable isotope; such isotopes are termed radio-active, because in breaking up they emit radiated energy. Carbon, the chemical designation of which is C (carbon being the chief constituent of coal), generally has an atomic weight of 12, and is therefore symbolized as C^{12}. But under the influence of the energy-filled cosmic radiation, nitrogen atoms in the topmost layer of the earth's atmosphere are converted into C^{14}, a radio-active carbon atom. A certain portion of this isotope thus appears in the air and is absorbed by the green plants together with the ordinary carbon that is utilized by the plant for nourishment. From an examination of the radio-activity in old plant sections their age can be approximately estimated.

By means of uranium reactors and huge apparatus called cyclotrons, so much energy can be added to ordinary inoffensive elements that they become unstable isotopes which merely try to rid themselves of this tiresome energy so that they may be at peace again. They are liable to explode so long as they still contain the energy; for when they revert to the peaceful state they emit energy in the form of radiation.

The artificially produced radio-active isotopes are usually cheaper than those occurring naturally, radium, for example. Thus in hospitals and research institutions at the present time the artificially radio-active cobalt isotope is being increasingly used instead of radium.

Furthermore the synthetic radio-active isotopes have the great merit that there is a choice available between various kinds, each of which may with advantage be used for its own special purpose. This is because they give off their energy at different rates. The term half-life period is applied to the time taken for half of the atoms to emit their radiation. The half-life period may vary from fractions of a second to millions of years. The half-life period for C^{14} (one of the isotopes of carbon) is 5,590 years; for radio-active cobalt 5.3 years; for phosphorus 14 days; for iodine 8 days; for copper 13 hours; for zinc 38.3 minutes; but for potassium, it is 12,700,000,000 years.

The radio-active isotopes are by degrees being used for innumerable scientific and industrial purposes, and to a greatly increasing extent in the service of medicine. To take one example: the thyroid gland is an organ that has the very special faculty of absorbing iodine from food and drinking-water, using it to make a hormone regulating the body's metabolism. If there is any suspicion of a thyroid disease, the patient is for some time given food and drink free from iodine; later he receives a certain amount of radio-active iodine in his food. By means of a geiger counter the number of atomic explosions of iodine in the thyroid gland is then registered. From this it can be determined whether the number of explosions is above or below the normal, and an estimate can be made accordingly of whether the gland has absorbed too much or too little iodine. As the half-life period for radio-active iodine is only 8 days, it is not long before most of it is destroyed, and that means that the patient does not have his cells exposed for a very long time to a harmful radiation effect.

Radio-active phosphorus, with its half-life period at 14 days, may in many cases be used as a means for the discovery of cancer in an organ.

Far stronger preparations than those used for diagnosis of a disease are needed for curing a disease. For example, to destroy a cancerous tumour in the thyroid gland a preparation is required 2,000 times as strong as the one used for testing the function of the gland.

Of the other radio-active isotopes, gold, for instance, can be introduced into the cavities of the body in fluid form, often inside a rubber container to prevent too much diffusion to other parts; on the spot the radiation then acts on the cancerous tissue, which has previously been located. The radio-active substance can also be injected directly into the cancerous tissue or into the artery that carries the blood to it. Here it is a great advantage that there are radio-active isotopes such as zinc, which has a half-life period of only 38 minutes.

However, with all these methods, which undeniably represent immensely valuable advances in medicine, we are risking an increase in the frequency of mutation. Hitherto this risk has hardly been given a thought in most hospitals. For a patient who is past the reproductive age, as is often the case with cancer patients in particular, the problem obviously does not exist. But if the patient is a person who will in all probability still produce offspring, the utmost caution should be observed in applying the dangerous radiation to the sex organs, and in any event the radiated energy that will probably hit the sex cells must be known. With the increasing incidence of cancer in people before and during the reproductive age, it can be anticipated that the use of radio-active isotopes will greatly increase. This additional risk for the future heredity of mankind must be carefully controlled.

It should be emphasized here that with hydrogen bomb explosions great quantities of the powerfully radio-active strontium isotope Sr^{90} are produced, which has a half-life period of 25 years. What is specially dangerous about this isotope is that our bones build the radio-active strontium atoms into their tissue as if they were harmless, normal calcium atoms. When the strontium atoms are settled in the bones, they irradiate among other tissues the red bone-marrow, where the blood corpuscles are formed, and that may lead to leukaemia and other cancer-like diseases. Moreover the possibility cannot be excluded that by remote action mutations may also occur in the sex cells.

Thus from the point of view of future generations hydrogen bomb tests are unjustifiable.

POSTSCRIPT

MANY readers will doubtless have gained the impression that the author of this book has painted a gloomy picture; this has been his deliberate aim.

When one is dealing with dangerous things, it is better to be over-cautious than too daring. Radiation is dangerous.

If however a majority of people become convinced that caution is required, then public opinion on the matter will be aroused, which is essential as a guarantee of continual caution. If this comes about—but it will require constant vigilance to achieve such a result—we may welcome the atomic age, profoundly rejoicing in the thought that by virtue of our intelligence and industry we have created the means whereby we and our descendants for many generations can 'subdue the earth'; this indeed is an absolutely necessary condition for the continued existence of the human race.

BIBLIOGRAPHY

The following short selection of titles is recommended to those interested in further reading.

AUERBACH, C. *Genetics in the Atomic Age*, London: Oliver and Boyd, 1956.

BRØNDSTED, H. V. 'The Significance of Experimental Embryology for Human Society.' *Impact of Science on Society*, Vol. IV, No. 4, 1955. (On the risk to embryonic development from radiation.)

FORD, C. E., and HAMERTON, J. L. 'The Chromosomes of Man.' *Nature*, Vol. 178, pp. 1020-3, 1956.

HADDOW, A. *Biological Hazards of Atomic Energy*. London: Oxford University Press, 1952. (A collection of lectures delivered by a number of scientists.)

HOLLAENDER, A. *Radiation Biology*. Vol. I: High Energy Radiation, parts 1 and 2. New York, Toronto, London: McGraw Hill, 1954. (A handbook containing exhaustive studies by specialists. Full information on the specialist literature is listed here.)

KALMUS, H. *Genetics*. Harmondsworth: Penguin Books. 1948.

LEA, D. E. *Actions of Radiations on Living Cells*. London: Cambridge University Press (new edition 1954). (A good introduction to the subject.)

TJIO, J. H., and LEVANE, A. 'The Chromosome Number of man.' *Hereditas*, Vol. 42, pp. 1-6, 1956.

WESTERGAARD, M. 'Man's Responsibility to his Genetic Heritage.' *Impact of Science on Society*, Vol. IV, No. 2, pp. 63-88. (A serious warning by a responsible Danish geneticist of international reputation.)

INDEX