The Nucleus in Relation to Heredity and Sex

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THE NUCLEUS OF THE LIVING CELL IN plants and animals has a most important relation to its activities and functions. It is clear, from the study of cells deprived of their nuclei in a way not to injure the body or cytoplasm of the cell, that the nucleus presides over its fundamental activities, such as growth, elaboration and use of foodstuffs, formation of new cells, and, finally—most important of all—over reproduction. It may, in fact, be stated that the nucleus of the cell in living organisms plays a role comparable to that shown in recent years to be enacted by the nucleus of the atom in the inorganic world.

Only slightly more than a quarter of a century ago, the genius of Rutherford revealed for the first time the nature of the atom and its all-important nucleus. With his truly epoch-making discovery, science passed from the era of the atom as a hypothetical "vortex ring" in an equally hypothetical "ether." Although the students of living matter have not been so frustrated by the exceedingly minute as have the physicists and chemists in the case of the atom, the living cell and its all-important nucleus require for their adequate investigation the highest powers of the microscope.

Equally important for the study of the living cell is the art of instantaneous fixation, at given moments, of its numberless activities. This is comparable to the study of the flight of bullets or similarly rapid movements by the instantaneous camera. Until relatively recently the student of the living cell has had to depend on somewhat slowly-acting preservatives dissolved in, or diluted by, water. The generalizations of cytology, or the science of the minute structure of the cell and its constituent parts, are based on preservative solutions in water of osmic acid, chromic acid, and various combinations of these with one another and with other reagents, as well as organic preservatives such as formaline, etc. These solutions penetrate too slowly to preserve accurately and instantaneously the organization of the fundamental structures of chromosomes at a given moment. We owe to a Beligan biologist (Carnoy) the earliest invention of reliable reagents causing instantaneous death or fixation. These fluids, variously formulated, depend for their rapid and instantaneous action on that extremely penetrating reagent, 100 per cent, or so-called absolute, alcohol. The shrinkage caused by this powerful reagent is controlled by the appropriate addition of a powerful swelling reagent, glacial acetic acid. These two, sometimes with the addition of other substances, for the first time gave us some accurate insight into the organization of the nucleus of the cell, in its active or kinetic stages. As a result of the improvement of Carnoy's procedures by various modifications, we are now in position to undertake at least the beginning of a recording of the structure and activities of the all-important active or kinetic nucleus of the living cell. The knowledge thus obtained appears to make necessary a fundamental revision of the "cell doctrine," particularly so far as the nucleus is concerned.

This is an objectively illustrated, general account of fundamental investigations on chromosomes, which appear to render necessary a revision of our views regarding the relation of the nucleus and its derivative chromosomes to heredity and the determination of sex.

The resting or quiescent nucleus is still relatively a closed book to the cytologist, on account of its extremely minute organization. The active or kinetic nucleus, however, presents structures, chromosomes, which are more easily resolved by our existing visual microscopes; unfortunately, the extreme magnifications supplied by the electron microscope are largely discounted by its very definite limitations in the investigation of active living matter. The relatively low magnifying power of our visual microscopes has limited cytologists in their studies to the examination of the largest available chromosomes of the active nucleus. These are found in the initial stages of reproduction. When a nucleus passes into the active or kinetic stage, it is resolved into a number of units, the chromosomes, which are definite in number in any given case. It was observed in the final decades of the 19th Century that the chromosomes in the active or dividing stages of the body cells were twice as numerous as in the case of the cells concerned in reproduction. It was further clear that when living beings, whether plants or animals, reach sexual maturity, a reduction from the double somatic number to the single reproductive number takes place. This was designated by an English biologist (Farmer) as meiosis, the Greek equivalent of reduction. The fact that the meiotic or reductive chromosomes achieve their halved number by taking on a double size made them particularly favorable, in comparison with other chromosomes, for study with the relatively feeble powers of existing visual microscopes. A further incentive to their study has been supplied by their relation to reproduction, for it has very naturally been believed that a study of the chromosomes on the brink, as it were, of reproduction might throw a revealing light on the process of reproduction itself.

As a result of their large size, which made them favorable objects for microscopic study, the meiotic chromosomes constituting the transition from the double or bodily (somatic) number of chromosomes to the single or reproductive (gametic) have been practically the entire basis of our knowledge of chromosomal structure, to the almost complete exclusion of other equally or even more important types.

Another important limitation of our knowledge of the organization of chromosomes has arisen from the idea that the reduction in chromosomal number in the meiotic stage was merely the result of the fusion of the chromosomes side by side in pairs as reduction or meiosis took place, technically known as synapsis or syndesis. This assumption is the result of a palpable disregard of the structure of the somatic or bodily chromosomes and, above all, of the organization of the hitherto completely structurally unknown reproductive or gametic chromosomes. In the actual state of our knowledge there is no authentic case of the union of chromosomes side by side, for a study of the organization of all types of chromosomes shows clearly that chromosomes become united invariably only end to end. Moreover, the union of chromosomes never takes place at the beginning of a nuclear division (as is assumed in current speculations as to the nature of meiosis or reduction), but at the end (telophase) of the immediately preceding division. It may be added that not only is the union of chromosomes in cell division characteristic of, and confined to, the end of the preceding division, but this situation is likewise an unfailing feature of all chromosomal unions, whether somatic, reproductive, or reductional.

The Structure of Chromosomes

Obviously, since chromosomes are an important and apparently a primitive feature of all nuclear division in the higher plants and animals, a knowledge of their intimate organization is absolutely necessary for an understanding of their relationship to hereditary transmission and the determination of sex. This is essential not only because of the fundamental importance of structure in this connection, but because general ignorance on this subject is unfortunately universally prevalent. Such information as is available on the true situation in this respect has appeared in foreign journals not usually accessible at this time to American cytologists. Further, since information supplied appears as yet to be regarded with general skepticism, a necessarily limited amount of objective evidence in the form of photomicrographs under high magnification is supplied in the present connection.

Fig. 1 represents the anaphase, or advanced stage of nuclear division, in the body cells of the root in the liliaceous genus, *Trillium*, characterized by the especially large size of its chromosomes, which makes them particularly favorable for investigation. The chromosomes are arranged in the two daughter groups characteristic of this stage. If the individual chromosomes are examined, it becomes obvious that they have a complex organization, consisting of a double spiral in which the coils (gyres) cross one another at somewhat regular intervals. This is particularly well seen in chromosomes in the upper left of the illustration. Similar organization has been universally described in large chromosomes of the meiotic division and has been generally regarded as an exclusive characteristic and most significant feature of this division. It has, moreover, been interpreted as representing the union of pairs of chromosomes derived from the parental egg and sperm. Since the condition now appears to be universally present in the somatic nuclear divisions, that interpretation obviously can no longer be logically accepted.

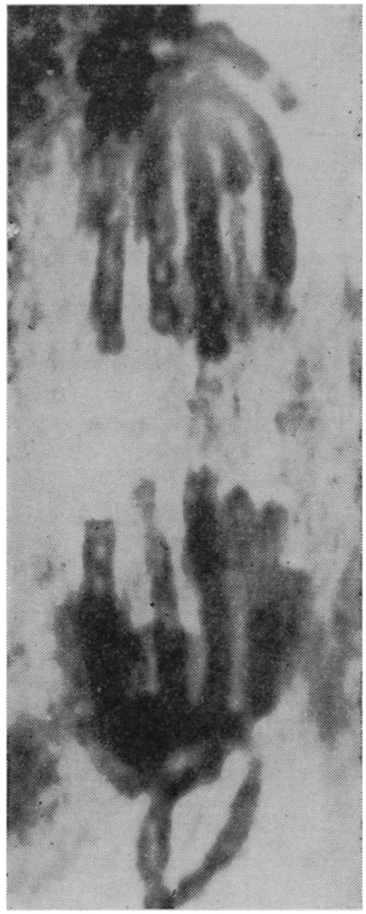

FIG. 1. Anaphase of a somatic division in *Trillium* (× 4,000).

Fig. 2 illustrates objectively in a photomicrograph a somatic division from a root of the common spiderlily, *Tradescantia*. The same complex and double structure can be clearly seen in such of the chromosomes as appear in sharp focus under the very high magnification shown.

Fig. 3 reproduces a comparable stage of division of the nucleus in the developing pollen grain of *Tradescantia*. The upper part of the dividing figure shows chromosomes evidencing the same double, crossing, spiral coils as are seen in the preceding two figures. It is thus objectively clear that all chromosomes have the same and identical structure and all are characterized by the presence of two spiral coils of chromatin (variously known in cytological literature as chromatids or chromonemata). The double chromosomal coiled structure is, accordingly, not confined to the meiotic, or reductional, chromosomes appearing at sexual maturity, as has been practically universally assumed in the genetical literature of the present time.

FIG. 2. Anaphase of a somatic division in *Tradescantia* (× 5,000).

FIG. 3. Reproductive division in the young pollen grain of *Tradescantia* (× 5,000).

Further, if the dual structure of the meiotic divisions marking the advent of the sexual cells or gametes were to be interpreted (as is generally accepted) as the result of the fusion of the double somatic equipment of chromosomes in homologous pairs of opposite sex, a *reductio ad absurdum* is reached, since meiotic, somatic, and gametic chromosomes all exhibit identically the same organization.

Fig. 4 shows a summary and slightly diagrammatic illustration of the situation described above in *Tradescantia*. In *a* appears a side view of the chromosomes at a late stage of nuclear division in a body or somatic cell. The double chromatin spirals can be easily distinguished. A comparable stage from the dividing gametic, or reproductive, nucleus of the pollen grain is shown in *b*. In *c* appears a division from the food substance, or endosperm, of the developing seed, which likewise shows identical features of chromosomal organization. In the three figures are represented side by side chromosomes of three distinct and typical categories, which, nevertheless, show identical internal organization. An earlier stage of division in the meiotic nucleus is illustrated in *d*. Here the chromosomes have become clearly doubled as a preliminary to division of the cell. The same stage in a gametic division in the young pollen grain may be seen in *e*. In *f* is shown a lateral view of the meiotic or reductional division. Obviously, in all these varied types of chromosomes the internal organization is identical. This situation, as has been shown objectively above by photomicrographs, is entirely unfavorable to the current views regarding the relation of chromosomes to inheritance.

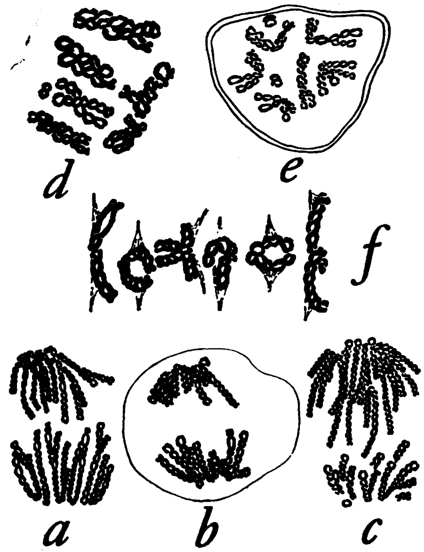

FIG. 4. Drawings of various types and stages of chromosomes in *Tradescantia*.

The present writer has previously pointed out in *Science* (*1*), on the basis of the facts of fertilization, as revealed by improved technique, that the chromosomes present in the fusing gametes, sperm and egg, as well as in the divisions of the fertilized egg itself, are identical in organization. It follows that the doctrine of the side-by-side, or lateral, fusion of chromosomes in the reduction division and the conclusions in regard to hereditary transmission based on that supposed condition have no sound basis in fact.

This situation eliminates also the contradiction that the reductional division preceding the formation of the gametes, in contrast to all other typical nuclear divisions, involves a fusion rather than a division of chromosomes.

There is a further important and, indeed, fundamental conclusion of current cytogenetics, negatived by the facts derived from the objective study of chromosomes by the improved and revealing methods outlined in an earlier paragraph. It has been assumed for several decades that the determination of sex may be brought about by male- and female-producing sex chromosomes, usually designated X and Y chromosomes. These are supposed to make their appearance in the meiotic stage and to persist throughout the somatic or body cell divisions. They have also been described and figured in the somatic divisions of *Drosophila* and other dipterous insects. The present writer has called attention to the erroneousness of this conclusion in such relatively favorable dipterous species as the mosquito (*Culex*) and the blackfly (*Simulium*) (*1*). This fallacy is obvious from a study of the course of chromosomal division in the cells of the body in the two-winged flies or Diptera, which makes it clear that the so-called sex chromosomes originate by division from the same mother chromosomes, exactly as is the case with the other chromosomes of the body. They are thus of identical origin and organization and consequently cannot be in any sense regarded as sex determinants.

The recent course of cytological investigation appears to make it clear that, as in the inorganic world, fundamental characters are concealed in atomic and molecular structures beyond the range of vision of our present visual and even electronic microscopes.

It may also be added that the supposed genes revealed in imperfectly preserved, reproductive chromosomes are merely the crossing points of the double spirals of chromatin, present in all chromosomes. A serious criticism of them in the capacity of structural bases of genetical genes is supplied by their insufficient number. Further, the crossing points of the chromosomal spirals are much more numerous in the earlier stages of the meiotic divisions and become still fewer and fewer as the development of the gametic cells progresses.

Reference

1. Jeffrey, Edward C. *Science*, 1945, **102**, 653–656.

Poland in the World of Science

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SCIENTIFIC KNOWLEDGE REPRESENTS A product of multilateral international cooperation. By pooling their individual contributions, scientists of various countries have made possible the developments in science and technology which constitute the foundations of our present civilization. In the course of their work, they are inspired by the thought that they are collaborating with other researchers of the world to solve scientific problems. In fact, international cooperation has always been a powerful stimulant in advancing human knowledge.

That the scientific world is truly a 'one world' has been triumphantly demonstrated by the release of atomic energy. This brilliant achievement in nuclear physics could never have been attained without the scientific and technological knowledge laboriously accumulated for the five decades since the discovery of radioactivity by the French scientist, Becquerel, and the separation of polonium and radium by Marie Sklodowska-Curie. Today it is in the best interests not only of science but also of human welfare to continue assuring close cooperation between the scientists of the world. Science is no longer a complementary element in each country's economic and political life but an indispensable part of it. In this atomic age, scientific progress constitutes the foundation of every nation's future; it is, in fact, the cornerstone of modern democracy.

Unfortunately, many countries devastated by the war are unable today to take an active part in advancing science and technology. Despite their long scientific tradition, they are practically left out in the scientific race toward a better and happier tomorrow. Perhaps the most tragic example of devastation that was brought about by the Nazi barbarians in the field of science was the destruction of scientific and cultural life in Poland. The Nazis pursued a ruthless policy of systematic extermination of intellectuals. Seventy members of the Polish Academy of Sciences perished, while 40–70 per cent of the total membership of university staffs were lost. One recalls here the case of Prof. Kalandyk, of Poznan, who served as a target for bottles thrown at him at a party for SS men. Hand in hand with the destruction of intellectuals went the eradication of Polish cultural life. Six thousand and four hundred schools, 3,350 cultural institutions, 16,000,000 books, and 700,000 collections and maps were destroyed by the Nazis.

In spite of this overwhelming destruction, Poland is making tremendous progress in restoring higher education. Most of the universities that existed in prewar Poland have been reopened, and seven new ones have