upon the sexual condition of the gametes in certain of the molds.

It is only by the further accumulation of facts in various groups of plants and animals that we may at length be in position to determine what if any unifying principle there may be in this wide-spread phenomenon of sexuality.

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The Biological Significance of Sexual Differentiation—A Zoological Point of View

The line of descent in multicellular animals is through a continuous or discontinuous series of sexual generations. In the latter case, there is alternation of generations, either of asexual and sexual or of parthenogenetic and sexual generations. So far as I know, the sexual generation is never absent in the first kind of alternation; there are, however, some parthenogenetic species in which males have never been found, though the structure of the females, or the natural history of the race, proves the former existence of males. There is only one feature common to all forms of sexual reproduction, and that is the union of ovum and spermatozoon to form a single cell, which has the capacity of developing into a new individual of the species. The biological significance of sex must, therefore, lie in the process of fertilization; and the interpretation of the fundamental significance of fertilization must be the answer to our problem.

Now fertilization is a more general phenomenon than sex itself, for it is characteristic of the Protozoa in the form of conjugation; and it appears to be a growing conviction among students of Protozoa that conjugation is universal in this group. Fertilization brings about biparental inheritance or amphimixis, and some have regarded this as its chief function, in view of the great importance of amphimixis for the process of evolution. But most zoologists regard amphimixis as a secondary function of fertilization, and find the chief significance of fertilization in the satisfaction of a periodic physiological need of the organism. The ovum usually requires fertilization as a stimulus to development; without it, in most animals, the processes of development either do not begin or soon cease. Observations on normal and artificial parthenogenesis demonstrate that it is not an indispensable requirement for development; however, in most parthenogenetic species fertilization-need arises in certain generations that alternate more or less regularly with the parthenogenetic ones; and those parthenogenetic species in which males are unknown have descended from sexual species, and moreover belong to specialized groups on one side of the main trend of evolution. Among Protozoa there seems to be a periodic need of fertilization to maintain the capacity of the species for reproduction.

We may then say, with the qualifications already indicated, that among animals at least the law of conjugation is as universal and imperative as the law of hunger. It is thus one of the most general of biological phenomena, with an element of obscurity in it that does not inhere in any other major problem of biology; for, as katabolism is combustion, the need of hunger to incite the individual to the taking of food is obvious; as the individual survives by adjustment to its environment, it must possess irritability and motility; but why the same food that satisfies for so long fails ultimately to support ebbing vitality among Protozoa, why the line of descent in Metazoa should pass through sexual generations —this is the mystery of physiology; and that salvation of the race should reside in

the union of particular cellular individuals, has in it none of the obviousness of the individual's preservation by the taking of food.

The nature of the periodic need for fertilization has been differently conceived by different writers. Weismann believes that fertilization-need has arisen in the course of evolution in order to ensure the advantages of amphimixis to the race; it has no fundamental physiological basis. R. Hertwig propounds the hypothesis that there is an innate tendency to acceleration of the vital processes, due to the gradual adaptation of nucleus and cytoplasm in their copartnership, which proves gradually harmful and ultimately fatal. Fertilization checks the acceleration by introducing a foreign nucleus, unaccustomed to the protoplasmic milieu; but the new partners in the vital process gradually accelerate the speed until a second fertilization again checks the dangerous pace. Fertilization thus marks the return to a state of stability from a state of extreme cellular lability. Herbert Spencer, on the other hand, regards the vital processes as tending towards a state of equilibrium or fixed stability; fertilization restores the labile condition of the cell. According to Geddes and Thompson, fertilization may be compared to mutual digestion and may have arisen from a nutritive want. "With the differentiation of the elements on anabolic and katabolic lines, the nature of the fertilizing act becomes more definite. * * * The union of the two sets of products restores the normal balance and rhythm of cellular life."

The point of view that has been, perhaps, the most acceptable to zoologists was stated originally by Bütschli, Engelmann, Minot and Maupas, and was based primarily on the study of conjugation in infusoria. It was discovered that, during the series of asexual generations, there is a gradual diminution of vitality expressed in a reduced rate of division and in certain morphological changes that may be collectively designated senescent. Conjugation changes all this; senile processes cease, the division rate is restored. Thus conjugation apparently reverses the process of senescence, causes rejuvenescence. By an extension of this idea it was assumed that in Metazoa the fertilized ovum starts out charged with abundant vitality, which is, however, gradually exhausted, and the race is saved only by fertilization, which is here also interpreted, by a reckless transfer of terms, as rejuvenescence.

The majority of zoologists appear to be agreed that fertilization-need is a primordial physiological condition, more than a mere adaptation to ensure amphimixis; and though there are weighty authorities on the other side, this point of view appears to me to be right, even though the theories of the nature of the need and its satisfaction are inconsistent. The idea of Spencer is too indefinite to serve either for foundation of a more extensive theory, or as basis for observation and experiment. That of R. Hertwig is in opposition to so many known facts as to be untenable. The conception of rejuvenescence has a flavor of mysticism, and involves a confusion of ideas. It implies that the gametes are senescent before fertilization, but the only significance of the term senescent is in its application to the soma. That the germ-cells before fertilization are old, in the sense that tissue-cells become old, would be asserted by no one. They are, on the contrary, the spring of eternal youth, and all that can be asserted objectively is the necessity of fertilization for their continual functioning.

Even in the case of Protozoa there is no reason for assuming that the part principally concerned in conjugation, the nucleus, is itself old; the cell-body un-

doubtedly becomes old, and after conjugation it apparently resumes its vigor. But the latter process is more correctly interpreted as renewal instead of rejuvenescence; the old body is sloughed off a little at a time and gradually renewed after conjugation from the germ-plasm, because it can not be cast off an entire dying body as in Metazoa.

I believe that Weismann is correct in his contention that the conception of rejuvenescence has not a shadow of support among the Metazoa, indeed would never have been conceived from what we know about the Metazoa themselves; and also that the conception is baseless as applied to Protozoa. The conception of germ-plasm and soma is as necessary for Protozoa as Metazoa, and the conception of senescence is unmeaning as applied to germ-plasm. But Weismann's conclusion that the Protozoa are potentially immortal does not follow; the protozoan soma is no more immortal than that of the Metazoa, and it is as little subject to rejuvenescence.

No theory of sex can be consistent that divorces the physiological significance from the causes of sex-differentiation. In the physiological significance, that is, in the nature of the fertilization-need, we must find the primary cause of sexual differentiation. Richard Hertwig has been one of the very few to recognize this axiomatic principle; but he nevertheless states two hypotheses, one of the physiological significance of fertilization, the goal and ultimate attainment of sex-differentiation, and the other of the causes of sex-differentiation itself, and these have no logical connection. The main value of Geddes's and Thompson's otherwise vague and unsatisfactory theory of sex lies in their appreciation of the connection between the physiological significance and the causes of sex-differentiation.

In Metazoa, fertilization is always selective, *i. e.*, between unlike gametes. Ovum does not fertilize ovum, nor do spermatozoa conjugate. It is true that a phenomenon known as fertilization by the second polar globule has been described in a parthenogenetic egg, but it is altogether improbable that it has the physiological value of fertilization. In Protozoa, also, fertilization is often selective, *i. e.*, between differentiated gametes, and there are various degrees of differentiation from conditions essentially similar to the reproductive cells of Metazoa, to relatively slight unlikeness of gametes; and the latter grades into the conjugation of like gametes, which seems to be the primitive condition. It is almost universally believed that selective fertilization does not exist when the gametes are alike; any two gametes may unite. It, therefore, follows that the fertilization-need is the same in both gametes (even when they are differentiated). And from this idea arises the inconsistency between theories of the significance and the causes of sex differentiation; for if the gametes are in the same physiological condition, their differentiation, and sex differentiation itself, can only be devices to secure gametic union.

But there is an alternative point of view, viz., that fertilization may be always selective, even when there is no morphological gametic differentiation. I am convinced that only on such an assumption can a consistent theory of sex differentiation be constructed. If gametes be physiologically different, even when they are morphologically alike, then morphological differentiation of gametes follows naturally as an expression of these physiological differences, and sex-differentiation as a further stage in the same process of evolution.

Now Calkins has clearly demonstrated the probability that fertilization is selective even when the gametes are morphologically alike. He showed that, in *Paramœcium*, one of the ex-conjugants in each case

has the greater vitality. He concludes: "This indicates that there is a physiological difference between *Paramœcium* gametes analogous to that existing between egg and spermatozoon."

It would seem that the view that species have periodic phases of inefficiency, corrected by fertilization, is well founded. But it is difficult to see how the union of two like inefficiencies may restore efficient functioning. I have much sympathy with Weismann's strictures on the hypothesis that the union of two senescent beings may produce one rejuvenated being. But if we conceive fertilization as always selective, *i. e.,* between physiologically differentiated gametes, then the fertilization-need must be different on the two sides; and this may be conceived in one of two ways: either the gametes represent plus and minus deviations, respectively, from the physiological mean, in which event fertilization might be supposed to be a reciprocal process; or one gamete may be supposed to act as stimulus and the other as the element stimulated, in which event fertilization would not be reciprocal, but one-sided. Now, fertilization in ciliate infusoria has always been supposed to be a reciprocal process, and the morphological phenomena are all in favor of this point of view; but Calkins's results indicate that only one of the ex-conjugants is benefited; the fertilization is one-sided physiologically.

In either event, union in the zygote would restore the physiological mean or condition of equilibrium, and the question would arise, how the differentiated conditions are subsequently produced. Nothing definite can be said about this at present; but it is obvious that the protoplasm does tend inevitably away from the condition of equilibrium towards one or the other differentiated condition; the direction of the tendency appears to be dependent on stimuli.

The objection may be raised that in some animals sex is certainly determined in the ovum at the time of fertilization, whereas, according to the point of view presented, fertilization is supposed to balance the physiologically differentiated conditions on which sex depends. Sexual determinateness of the fertilized ovum may, however, be interpreted to mean only that the sex-determining factors, primitively external, have been replaced by internal conditions in these cases. It is certainly not an illogical position that physiological neutrality in regard to sex may coexist along with internal conditions that absolutely restrict sexual differentiation to one direction.

In his thoughtful and suggestive paper on 'The Phenomena of Sex Differentiation,' Watasè comes to the conclusion that

> The organism is either a male or a female, not by the difference of primary sexual characters alone, but by the difference which saturates the whole of its entire structure. Such a difference is, however, neither absolute nor permanent. It is a temporary differentiation of protoplasm into one of two different directions, and sooner or later comes back to the original neutral or non-sexual state from which it started, thus manifesting the phenomenon characteristic of all protoplasmic irritability.

His point of view is instructive; there is a sexually indifferent stage of the organism corresponding to the period of union of the germ-nuclei; sexual differentiation is a phenomenon of irritability or response to stimulus, which lasts throughout the life history of the growing organism; 'and the recurrence of the irritable condition corresponds to the production of the unicellular embryo.' Sex differentiation is thus one of the phenomena of irritability, and it differs from other phenomena of this class only in the slowness of its rhythm.

Watasè's conclusions were based on the observations of Auerbach, himself and others, that the staining reactions of the egg and sperm nucleus are entirely differ-

ent during the earlier stages of their existence, but that these differences disappear at the moment of fecundation. It has since been shown that the difference in staining reaction of the germ nuclei is probably of secondary significance only, but the view that a primary physiological difference between the germ-nuclei exists, is not necessarily excluded.

The question has arisen whether we are to deny the old biological conception of a sexually indifferent stage in the life history? It seems to me that this conception is as necessary and fundamental today as it ever appeared to be, and that we can not depart from it without involving ourselves in absolutely hopeless theoretical difficulties.

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Sex Determination in Relation to Fertilization and Parthenogenesis

It is not an easy task to attempt a brief discussion of the relation of sex determination to fertilization and parthenogenesis; for the fact may as well be admitted at the start that we are not yet in a position to make any general statement as to what that relation is, and it is my impression that the subject is not yet ripe for discussion. We are not yet, I think, in a position to conclude with certainty in any single case that fertilization can be considered as a sex-determining factor, not even in the classical case of the bee. Even in cases which at first sight seem clearly to show that fertilization is such a factor, consideration will show that we can not, or at any rate have not, shut out the possibility that fertilization may be determined by sex rather than the reverse. There is the same uncertainty regarding the relation of sex production to parthenogenesis. There is no constant relation between these two processes, for the parthenogenetic eggs of a single individual may in the same species produce females only, males only, or both males and females. Both fertilization and parthenogenesis, in fact, present us with a series of relations to sex production in which the common factor, if there be such a factor, still eludes us.

There are two primary data which, I think, must be taken as our point of departure in any attempt to discuss these problems. The first is the long-known fact that in a few cases, of which the best known are those of *Dinophilus apatris* and *Hydatina senta,* the eggs are visibly distinguishable by their size as males and females, before fertilization or even maturation. Neither fertilization nor maturation, accordingly, can here be a sex-determining factor. We only know, if the results of Maupas and Nussbaum on *Hydatina* and the more recent ones of von Malsen on *Dinophilus* be well founded, that in these cases the ratio between male eggs and female eggs may be modified by conditions of temperature, or nutrition, or both, that affect the mother before the eggs are laid; but the true interpretation of this is still very far from clear. The second primary datum is that in many insects, and probably in many other air-breathing arthropods, the spermatozoa are predestined in the constitution of their nuclei, as males and females, or better, male-producing and female-producing forms, in equal numbers. Here, however, our actual knowledge ends, so far as fertilization is concerned. We do not know in any single case whether the predestination exists in both eggs and spermatozoa in the same species. Until we can be sure on this point it is almost idle to speculate on the subject; for if such a double predestination exists there must obviously be a selective fertilization, such that each form of egg is fertilized by the appropriate form of spermatozoon; and if this be so, sex is not determined by fertilization, but fertilization by sex. Until this ques-