The data at present available from the field of experimental embryology and from the experimentation concerned with regeneration and regulation in the adult organism lead us to conclude that the animal which we call typical is not the maximum expression of all of its inherent formative potentialities. The facts necessitate the postulation of a mechanism whereby development is checked as well as one whereby it is initiated.

The following is a preliminary report of a series of investigations performed in an attempt to demonstrate the actual existence of such a mechanism.

Inhibitory Dominance.—Rand and Browne (1926) from a number of grafting experiments and Rand and Ellis (1926) from their work with individuals of Planaria maculata which had been made double-headed by a longitudinal splitting in the mid-line concluded that removal of one of the two heads may be followed by its regeneration at a retarded rate, or by non-regeneration in which event the animal resumes the form of a typical single-headed worm. The non-regeneration was said to be due to an “inhibitory dominance” exerted by the remaining head.

The above experiments dealing with double-headed planarians arising from the splitting operation have been extended and modified so that data from 225 cases involving a wide range of duplex forms, some with equal and others with unequal heads, are now available. Careful measurements of the duplicated regions and of the common posterior part were made, and the level of transection carefully noted.

It has been definitely demonstrated that removal of one of the heads from a double-headed individual of Planaria maculata may result in the regeneration of an aborted head, in regeneration at a retarded rate or in no regeneration (Goldsmith, 1930a). The failure to regenerate is not due to the lack of regenerative capacity, nor can it be viewed as being due to the absence of the nervous or digestive systems. This failure is correlated with the presence of the remaining head. The effectiveness of this head as an inhibitor is in turn correlated with: (1) its size in relation to the size of the removed head; (2) length of stump, i.e., the length of the duplicated region following head removal; (3) body-level, i.e., level on the antero-posterior axis at which the incision for removal of the supernumerary head is made.

It was found that the frequency of head regeneration in the double-
headed worms was greatest in a zone lying between a level somewhat posterior to the eyes and a level anterior to the pharynx.

Induction.—Child (1927) produced secondary hydranths in Corymorpha by a series of incisions radiating from a common center. Utilizing a similar technique (Goldsmith, 1930b), and also those of faradic stimulation and cautery (Goldsmith, 1933), it was found possible to induce supernumerary outgrowths which ranged in form from mere small bulges or indifferent conical outgrowths to head-like structures possessing typical eyes. In a number of cases supernumerary eyes resulted from the operation.

The results derived from the three types of injury to individuals of Planaria maculata agree in that the structures developing after stimulation in the pre-pharyngeal region differentiate to a greater extent than do those arising after stimulation in the post-pharyngeal region.

Cautery experiments with Procotyla gave negative results.

Discussion.—Santos (1929, 1931), using Planaria maculata and Planaria dorotocephala, performed a series of homoplastic and heteroplastic transplants of the region of the cephalic ganglia. In its new location the graft developed into a head-like structure and then induced an outgrowth from the host body (part of the outgrowth appeared to arise from donor tissue). Although the supernumerary structures produced by non-specific stimulation closely resemble those produced by grafting cephalic ganglia the sequence of events is quite different. In the former the injured region becomes elevated. This elevation increases in size so that it protrudes markedly from the host, and eyes and auricles may develop in the distal portion of the structure so formed. This behavior and that of the Corymorpha individuals described by Child would then necessitate shifting the emphasis from the agent utilized (injury or implantation of tissue) to the zone to which the agent is applied or transplanted.

From two contrasting types of experimentation, it has been made apparent that a zone lying between a level somewhat posterior to the eyes and one somewhat anterior to the pharynx is of special significance in that: (1) the frequency of regeneration of one of the heads of a double-headed form is greater, and (2) structures arising after non-specific stimulation differentiate to a greater extent in this zone.

Further, these results are in agreement with recent experimental cytological and chemical findings.

Curtis and Schulze (1934) have concluded that certain cells—formative cells—are present in the parenchyma of planarians. They maintain that these cells have the capacity to give rise to all new tissues and that their number is greater in members of species with a high regenerative potency (Planaria maculata) than it is in worms with a low regenerative potency.
(Procotyla fluviatilis). They further state that the number of formative cells is greatest in a zone lying somewhat posterior to the eyes and somewhat anterior to the pharynx.

Buchanan (1933) criticizes the view that formative cells are to be correlated with regeneration. He states in part (p. 197) "...the inhibitory effect on head formation is much greater if the level of origin of the piece is shifted posteriorly than if the size of the piece is reduced. Presumably, in reducing the size of the fraction from one-half to one-eighth the total length of the animal, one reduces the number of neoblasts and the quantity of nerve tissue correspondingly; yet the reduction in head frequency is small as compared with the effect of shifting the level of origin of the piece."

It appears to me that the important factor is the number of formative cells per unit volume, and this number is smaller at a more posterior level. By reducing the size of an anterior piece one does not reduce the density of neoblasts; on the contrary since injury may cause these cells to divide (Flexner, 1898; Curtis, 1902) the number would be made even higher.

Coldwater (1930) has reported that the glutathione content in Procotyla is low while that in Planaria agilis is high; further, that the glutathione content is higher in regenerating tissues. These results Coldwater correlated with the formative cell content. Curtis (1928, 1930) has shown that the formative cells are destroyed by x-ray. Exposure of glutathione to radium emanation decreases the free SH (Hammett, 1932).

Hammett, from an extensive series of experiments employing a variety of plant and animal forms, claims that the sulphydryl group acts as an accelerator of cell division which in turn "enhances differentiation," and that the partially oxidized derivatives retard cell multiplication.

In view of the previous investigations in part here cited and of the experimental results briefly presented it is suggested that the high degree of differentiation attained by the outgrowths induced by the cautery operation and the ineffectiveness of the inhibitory mechanism in the pre-pharyngeal zone (above referred to) are correlated with a high formative cell number and a high SH content in that region. It is possible that the inhibitory action may be exercised by means of a partially oxidized derivative of SH. It must be borne in mind that sulfoxide arising as a product of the partial oxidation of the SH may be formed in the region of injury and also in small amounts throughout the body. However, it may be urged that these quantities are not of themselves capable of exerting a restraining influence sufficiently powerful to prevent regeneration. If the above interpretation be correct then the difference in behavior in the regeneration of a head in a single-headed animal and that in a double-headed animal would be due to the additional sulfoxide arising in the region somewhat posterior to the eyes.
Finally, it is suggested that regeneration in Planaria maculata is not to be accounted for in terms of "head stuffs" and "tail stuffs." Rather it is to be regarded as due to the innate property of the formative cells to respond to an injury by proliferating and differentiating to the utmost—in planarians the height of differentiation is expressed in head formation. The degree of differentiation which the regenerate undergoes depends upon the ratio of the regenerative potency present in the region of injury to the inhibitory action exerted by the apical end of the worm.

Acknowledgments are due to the Department of Biology of New York University (Washington Square College) for assistance given the author during 1929-31.

Buchanan, J. W., "Regeneration in Phagocata gracilis (Leidy)," Physiol. Zool., 6, 185–204 (1933).


Rand, H. W., and Browne, A., "Inhibition of Regeneration in Planarians by Grafting: Technique of Grafting," these PROCEEDINGS, 12, 575–581 (1926).

Rand, H. W., and Ellis, M., "Inhibition of Regeneration in Two-Headed or Two-Tailed Planarians," Ibid., 12, 570–574 (1926).