Polarity : from dipoles to biopolarizations. II. Addenda and indexes

Autor(en): **Turian, Gilbert**

Objekttyp: **Article**

Zeitschrift: **Archives des sciences et compte rendu des séances de la Société**

Band (Jahr): **42 (1989)**

Heft 1: **Archives des Sciences**

PDF erstellt am: **22.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-740081

Nutzungsbedingungen

Die ETH-Bibliothek ist Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Inhalten der Zeitschriften. Die Rechte liegen in der Regel bei den Herausgebern.
Die auf der Plattform e-periodica veröffentlichten Dokumente stehen für nicht-kommerzielle Zwecke in Lehre und Forschung sowie für die private Nutzung frei zur Verfügung. Einzelne Dateien oder Ausdrucke aus diesem Angebot können zusammen mit diesen Nutzungsbedingungen und den korrekten Herkunftsbezeichnungen weitergegeben werden.
Das Veröffentlichen von Bildern in Print- und Online-Publikationen ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Die systematische Speicherung von Teilen des elektronischen Angebots auf anderen Servern bedarf ebenfalls des schriftlichen Einverständnisses der Rechteinhaber.

Haftungsausschluss

Alle Angaben erfolgen ohne Gewähr für Vollständigkeit oder Richtigkeit. Es wird keine Haftung übernommen für Schäden durch die Verwendung von Informationen aus diesem Online-Angebot oder durch das Fehlen von Informationen. Dies gilt auch für Inhalte Dritter, die über dieses Angebot zugänglich sind.

Ein Dienst der *ETH-Bibliothek*
ETH Zürich, Rämistrasse 101, 8092 Zürich, Schweiz, www.library.ethz.ch

http://www.e-periodica.ch

343 408

POLARITY

FROM DIPOLES TO BIOPOLARIZATIONS

II. ADDENDA AND INDEXES

by

Gilbert Turian

ETH ZÜRICH
18. Jan. 19..
BIBLIOTHEK

Ce travail est la suite et le complément de celui intitulé POLARITY, paru en 1989 dans le volume 42, fascicule 1, des *Archives des Sciences.*

La numérotation des pages poursuit celle dudit travail. Nous conseillons donc à nos abonnés de classer ce supplément à la fin du fascicule 1, vol. 42.

This paper supplements the review entitled POLARITY (Arch. Sci. 42: 1-323, 1989) and should be classified at the end of vol. 42, fasc. 1.

Société de Physique et d'Histoire naturelle
Genève 1990

ISSN 0252-9289

POLARITY
FROM DIPOLES TO BIOPOLARIZATIONS

II. ADDENDA AND INDEXES

BY

Gilbert TURIAN*

Polarity is a problem of wide interdisciplinary interest that we have attempted to survey in its widest span from its atomic to its embryogenic, plant and animal levels in the Archives of 1989 reprinted as book **I** (Turian, 1989).

Primeval polarity is bipolar, founded on the separation of two equal but opposite electric charges. Consequently, even apolar molecules are intrinsically electrically polarized but with a symmetrical distribution of their opposite (+ and −) electric charges and therefore they lack in electric polar moment. Similarly, apolar morphological biostructures are examplified by spherical cells (certain eggs, etc.), initially deprived of heterogeneously distributed components, and which being identical with their mirror image can be also considered as achiral.

The whole universe is electrically neutral and, by necessity, contains rigorously equal numbers of opposite electric charges (10^{40} of protons and of electrons, see Souriau in Brack *et al.*, 1989) even though it is filled with electric dipoles from the minute water molecules to giant cosmic dipoles, a basic requirement for its physico-chemical and biological functionings. However, in its wider expression, polarity spans not only pure electric and magnetic phenomena but also chemostructural (chiral), biomolecular (cytoskeletal elements) and spatio-temporal developmental processes. Our survey had therefore to encompass them in their whole span from monopoles to multipoles as following:

1) *monopoles,* electric (+ or −) or magnetic (still elusive north or south isolated poles) as well as homochirals (l- or d-enantiomers) and monopolar, elongating biostructures such as microfilaments (actin), microtubules (tubulins), multinucleate cells such as hyphae and neurites;

---

* Laboratoire de Microbiologie générale, Sciences III, Université de Genève.

2) *dipoles,* basically electric (+ and −) or magnetic (north and south poles), but also heterochirals (l + d-enantiomers) as well as morphogenetic homodipoles in the twice-budded or -germinated yeasts or fungal spores and heterodipoles in the developing eggs of plants and animals;

3) *tripoles,* electric (+ − + as in thunderclouds, see addendum) or morphogenetic as in iris flowers!

4) *quadrupoles,* electric (radio-frequency electric traps and nuclear coupling, see addendum) or morphogenetic as in four- (multi-) budded yeasts and germinated fungal spores;

5) *multipoles* as exhibited by cells such as amoebae or fungal spores outgrowing n (>4) pseudopodia or germ tubes, respectively.

During the second half of 1989 and first trimester of 1990, we have noticed a few omitted significant papers as well as newly published ones, related to dipoles and biopolarities. We have registered them below by following the sequence of the eight preceding chapters and, parallely, added two subject and taxonomic indexes. Their item entries cover the main book (**I,** 1989) and these first addenda (**II,** 1990).

I. ATOMIC POLARIZATIONS

A. ORIGINS

A fourth state of matter is the plasma state which is formed when a gas is heated to such high temperatures that it becomes partly or fully ionized: "electrons are torn off the atoms in the gas, leaving a stream of negatively charged free electrons and positively charged ions"(Peratt, 1990). Suggestively, the term plasma proposed in 1932 by Langmuir evokes "the unstable almost lifelike behavior of the ionized material". According to plasma cosmology, "the universe has been and remains a veritable sea of charged particles interlaced with complex magnetic fields and electric currents. Many among the cosmologists therefore conclude with Peratt (1990) that "the universe may have evolved not with the Big Bang but from a vast sea of plasma". However, the theory of primordial explosion and of the shaping of the universe by gravitational rather than by electromagnetic forces keeps strong proponents (Rees, 1990).

In the evolutive perspective from the inert to the living matter, the atom of hydrogen (H) could be viewed as forming "le couple divin"(Turian, 1990) displaying the electron, mobile as a male cell around the passively "courted" proton, as female cell, a most fertile association indeed concretized in the bioenergetics through the ATP-generating redox scale ($2H^+ + 2e^- + O = H_2O$, see **I**, IV.B.2.c).

B. SYMMETRY – POLARITY

The whole world appears to be chirally asymmetric from the scale of elementary particles upward. This leads Hegstrom and Kondepudi (1990) to ask the questions, as we did (**I**) for related polarities "How do the asymmetries arise? Are chiral symmetries at one level linked to those at another, or are they independent?"

Chiral asymmetry must therefore be first studied at the scale of elementary particles. Indeed, there is symmetry within an atom only when it is regarded as governed by the electromagnetic force and its associated property of conservation of parity. The additional weak force (involving W^+ and W^- gauge bosons) gives rise to a violation of parity and consequently an asymmetry between the electrons and the nucleus in the atom (Bouchiat and Pottier, 1984). Chiral asymmetry at the subatomic level is thus fundamentally connected to parity nonconservation. One result of this asymmetry is that nuclear β decay, which is governed by the W force, produces mostly left-handed electrons. Consequently, electrons of matter are polarized with a left helicoidal coil while positrons of antimatter are right-directed. However, such chiral

effects of the electroweak W and Z charges leading to a distinction between left and right chirals are strictly valid only when the electrons are travelling at the high energies near the speed of light (Hegstrom and Kondepudi, 1990).

An important consequence of chiral asymmetry at the *subatomic* level is that it causes a chiral asymmetry at the higher level of *atoms*: under the influence of the Z weak force, the electron orbit becomes a right-handed helix in the vicinity of the nucleus. However, the asymmetric Z force is so small that its effects on the chemical properties of *molecules* has not (yet) been observed (Hegstrom and Kondepudi, 1990). That such a mechanism affecting the production rate of L- and D-amino acids can indeed exist in nonequilibrium chemical systems was shown theoretically by Kondepudi and Nelson (1985, see **I**).

The problem of equivalence which has been upheld about left and right (see II.D) also arises "with respect to positive and negative electricity" as commented by Weyl (1952) in his book entitled "Symmetry" in which he also discussed relationships between quantum mechanics and symmetry. This author also assumed that "the primary polarity as well as the subsequent *bilateral* symmetry come about by external factors actualizing potentialities inherent in the genetic constitution" (see VII-VIII in **I**).

As already expressed by Pierre Curie "symmetric systems behave in a symmetric fashion". However, such Curie's principle is contradicted by the occurrence of spontaneous symmetry breaking which occurs when a perfectly symmetric system takes up a state with less symmetry (Field and Richardson, 1989). An example of the phenomenon is the change of form produced by compression of a cylindrical shell initially endowed with a perfectly *circular* symmetry.

The principle of "cosmologie symétrique" has been further discussed by Brack *et al.* (1989) in relationship with the equivalence between matter (proton + electron) and antimatter (antiproton + antielectron). Among previous books concerned with the principle of symmetry there are those cited by Weyl (1935), namely Jaeger (1917) and Hambidge (Dynamic Symmetry, 1920), completed by Jaeger (1925) and, more recently, those by Nicolle (1950) and Caillois (1973) as well as Hargittai and Hargittai (1986).

C. Electric bipolarization

2) *Electric dipoles*

The hydrogen atom (H) can be considered as the primordial electric dipole when we consider that its electron or unit of negative charge is probabilistically positioned on a peripheral orbit around the positive proton according to the classical image of a planet circling the sun (Fig. 1B, in **I**). However, when the atom is placed under

strong stimuli such as a constant magnetic field or exposed to electromagnetic radiation in the form of microwaves, either of these strong stimuli disturbs the orbit of the electron and pushes it into chaotic, unpredictable motion. Eventually, the electron atom is ionized, i.e. its electron has so much energy that the pull of the proton can no longer hold it, and the electron is torn away. According to quantum mechanics, the electron is not considered as a particle orbiting the proton, but as a rather nebulous "wave packet". Ionization high energy will delocalize the wave packet, namely "the electron will become "spread out" over several energy levels", an event corresponding to "the chaos in the classical motion of the electron" (Pool, 1989).

Protons and neutrons, the two types of nucleons, can be examined "by observing electron or muon scattered off them with a large transfer of momentum to one of their constituent particles or partons" (Roberts, 1990). As for the proton, its simplest properties are dependent on the three valence quarks, two "up" (u^+) and one "down" (d^-) (see **I**, I.C.2), each of which carries a spin of 1/2. These are polarized so that the u^+ quarks contribute 4/3 of the proton's total angular momentum (also 1/2), and the d quark $-1/3$. The distribution of polarized quarks can never exceed the distribution of unpolarized quarks (further discussion in Roberts, 1990).

The neutron (1 quark u^+ and 2 quarks d^-, see Cline, 1988) has also an electric-dipole moment, the upper limit of which has been recently measured (Smith *et al.*, 1990). The interest of neutron's electric-dipole moment is that "it would violate the combination of charge conjugation invariance and parity known as CP symmetry. As such, any electric-dipole moment would take the opposite sign for the antineutron, and thus discriminate between matter and antimatter" (Ellis, 1990).

Quantum theory holds that two photons emitted by a particular light source share their similarly oriented polarization. According to Clauser and Freedman's experiments recently recorded by Linden (1990), "a change in one photon did alter the polarization of the other" as if they were not separate objects and thereby obeying to the laws of quantum mechanics also applied to other "wave particles" such as leptons (electrons, etc).

In a search for understanding the charging of storm clouds, and contrarily to previous conclusions from Wilson and Simpson (see Williams, 1988) that electrical structures of thunderclouds were either a positive dipole (Wilson) or a negative dipole (Simpson), their actual structure is tripolar rather than dipolar. The correct explanation for this tripolar structure of thunderclouds is now known to lie in the microphysics of charge transfer between graupel particles (soft hail) and ice crystals (Williams, 1988).

3) *Polarized conductivity*

In a semiconductor the electrons move through an array of constituent atoms arranged in a crystalline lattice. Electrons move with great ease through gallium

arsenide circuits. This compound is made into bipolar transistor devices by depositing it in three layers: electrons n-type doping, holes p-type base and n-type collector. These compose light-emitting diode of gallium arsenide alloyed with aluminium. Gallium arsenide photodetectors respond faster than silicon ones. They can also detect light by reversing the reaction and the resulting photodetector converts the flash signal to electronic pulses. Such optoelectronic computing systems can be linked by optical fibers which greatly increase the efficiency of the digital computing circuitry (Brodsky, 1990).

D. Magnetic polarization

1) *Cosmological level*

The sun's magnetic field can affect many aspects of the sun's surface and atmosphere. It oscillates along a 11-year variation of sunspot number. Measurements of sunspot spectra (Zeeman effect's analysis) showed that the strength of the magnetic fields around sunspots is thousands of time stronger than the earth's field. Most spots occurred in paired groupings that resemble giant magnetic dipoles roughly parallel to the solar equator. According to Foukal (1990), the great astronomer Hale already announced in 1924 that this switch in polarity occurred at each activity minimum, in the midst of a 22-year solar magnetic cycle and was a basic feature of the sunspot cycle. The largest areas of single magnetic polarity are the sites of spot formation. These solar magnetic changes may have their effects on the earth's periodic climate changes.

2) *Magnetic fields*

The discovery of ferroelectric crystals such as barium titanate ($BaTiO_3$) offered an electrically switchable, two-state device with which one could encode the 1 and 0 states required for the Boolean algebra of binary computer memories. A tetragonal ferroelectric crystal has two polarization states in which the centrally located Ti^{4+} ions are involved through their displacement up or down with respect to the other ions (Ba^{2+} or Pb^{2+}, O^{2-}). In a crystal of $PbTiO^3$, for example, there would then occur regions in which the polarization is up and regions it is down, called "ferroelectric domains" (Scott and Paz de Araujo, 1989). Most important for memory applications, the polarization of the entire crystal can be switched from up (+1) to down (0) by reversing the applied field. This ferroelectric memory progressively fades when the amount of switched charge decreases with use or by retention failure when the stored charge decreases to a level where the + or − state of polarization cannot be sensed.

All ferroelectric materials display a hysteretic behavior relating polarization and applied field, so that there is a nominal threshold (coercive field) above which the polarization changes sign.

4) *Spin polarizations*

Dipolar interaction between two nuclear spins depends on size and orientation of the magnetic moment as well as on the distance. In NMR spectroscopy which is based on the Zeeman phenomenon (Ernst *et al.*, 1987), nuclei with a kinetic moment of spin I higher than 1/2 have a quadrupolar (Q) electric moment. The nuclear quadrupolar resonance (NQR) is bound to a nonspherical symmetry in the distribution of electric charges on the nuclear volume. This NQR can only be observed on a limited number of nuclei but is helpful in the study of the electric structures of chemical bonds (Lucken, 1969).

E. Light polarization

A light ray can be polarized by reflection on a polarizer and the intensity of the reflected ray received on an analyzer varies with its incident angle. The proportion of polarized light in the light ray or the rotation of the polarization plane of light are measured with a polarimeter (Pariselle, 1936).

II. MOLECULAR DIPOLES AND CHIRALS

A. Electric dipole moments

Dipolar electric moments and dielectric polarization have been surveyed by Errera (1928, 1935). Further study of the dielectric response of matter to an applied electric field has contributed to the measurement of molecular dipole moments (Price, 1969). The induced dipole moment per unit volume or polarization consists of two components: a *polarizability* one which arises from the distorsion of the electronic distribution of the substance, and an *orientation* component. Farley and McClelland (1990) have demonstrated that even in collisionless molecules, "hot isolated polyatomic molecules can reorient in response to an external field, thereby giving rise to this second component of polarization".

B. Mineral dipoles

1) *Dipolar water*

Among recent and complementary knowledge about water biophysics and relevant to polarity, mention can be made of Saenger's 1987 review. It mainly concerns the relationships between hydration water and hydrogen bonds. Hydrogen bonding dynamics involves flip-flops and movement of water along the surface of macromolecules. Water would not have its particular properties if the molecules were not associated by hydrogen bonds O-H···O. If the O-H group is involved in hydrogen bonding it becomes polarized (see II in **I**). In the association of water molecules to the surface of proteins or nucleic acids, hydrogen bonding of type (water) O-H···*Y* is the main attractive force. When the O-H···O bonds all run in the same direction, this is called *homodromic*; it is indicative of the influence of the cooperative effect. When a water molecule donates two hydrogen bonds this gives rise to *heterodromic* situation, where hydrogen bonds are randomly oriented.

According to the idealized structural model for water presented by Finney (1982), the simplest picture of the molecule "assigns partial charges to the two hydrogens and the two lone pairs which are considered to be disposed in an approximately tetrahedral manner. Each molecule is capable of forming four hydrogen bonds to neighbouring molecules" (see also **I**). Among the three proposed models of the water-water hydrogen bond, the PE model (water molecule electron distribution in terms of an electrical multipole expansion, see Barnes *et al.*, 1979) represents the water molecule electron distribution in an electrical multipole expansion. According

to Finney (1982), "the experimental dipole moment and quantum mechanical quadrupole are used, together with a dipole polarizability to try to handle the cooperative effects". Switching on polarizability in the PE model would therefore affect only the dipole-dipole and dipole-quadrupole energy terms (Finney, 1982).

The local dipolar field of protons of liquid water is averaged out by fast isotropic rotation and translational diffusion, and this gives a single narrow line in the NMR spectrum. In a molecular or biological system which can restrict water motion, causing an anisotropic averaged orientation, the NMR spectrum of the preferentially oriented water molecules can be given by a line pair or doublet. Lenk *et al.* (1980) have reported such NMR doublets spectra due to "structured" water in plant systems.

A typical example of efficient proton translocation across or along the surface membrane is the movement of protons across a cell membrane after their generation in some oxidation process. A high level of proton conductivity is extremely rare in crystalline solids. Thomas and Farrington (1982) have proposed that the proton conduction mechanism in one of the very best crystalline proton conductors so far studied ammonium/hydronium β"-alumina is a useful model mechanism for biological proton transfer. This proton conduction mechanism deduced from an accurate single crystal neutron diffraction study involves a classical Grotthus-type mechanism (see below).

In relationship with bilayer membranes (see IV.B.2) it should be pointed out that "an ion in water is stabilized by the favorable interactions of the water dipoles, the hydration energy. To remove an ion from water and place it in the middle of a membrane is unfavorable because of the loss of this hydration energy". The most successful model for quantifying this is the Born model described in Gennis (1989). In addition to this Born energy, a second component due to the polarization arises at the dielectric interface. An "image energy" results from the "presence of a charge on one side of the interface which causes the dipoles in the medium on the other side to reorient".

Cell water is modified by solvation which arises when water abuts a cell surface. Molecules become restricted in their motions and a greater proportion of them have four (rather than three or fewer) hydrogen bonds with their neighbours. Water modified in this manner is called vicinal (see **I** and Drost-Hansen and Singleton (1989).

Virtually all of the water in cells is considered to exist as polarized multilayers arising from fixed charges on extended protein surfaces. Cardinal sites exist on these particular proteins, the degree of binding for a given ion being influenced by a number of factors. Clegg (1982) further commented "ATP binding at the cardinal site leads to cooperative alterations and the selective accumulation of K^+ over Na^+, and generates the polarized multilayers of water; ATP splitting and the removal of ADP results in a movement of the system to a lower energy state in which the ion selectivity is lost as is the polarization of water".

Protons can be transferred along lipid/water interface in the absorbed water molecule network by a Grotthus-type mechanism (ref. in Tocanne and Teissié, 1990, see also IV.B.2.a).

C. Organic dipoles

2) *Multiple molecules (polar chains)*

Charge transfer molecular interactions are of high significance in biology (Sklifkin, 1980). Electrons are delocalized in molecular conjugated systems (alternate single and double bonds). The polarization of these molecules is enhanced when they carry hydroxy-substituent(s) which behave as electron-attracting groups. Consequently, Pont and Pezet (1990) could suggest that "the polar interaction of these molecules with membraneous proteins could lead to a destruction of the cellular membranes by depolarization" (see IV.B.2.d). This could account for the biocidal effects of highly conjugated phenol derivatives such as the natural hydroxystilbenes which are efficient protectors of grape berries against the grey mold *Botrytis* (Pont and Pezet, 1990).

D. Chiral molecules

Pasteur (1884, see **I**) audaciously extrapolated from molecular asymmetry the famous aphorism "la vie est apparue dans une brisure de symétrie". If we equate asymmetry and polarity, this would therefore mean that polarity is basic to the arisal of living matter.

From atoms to human beings, nature is asymmetric with respect to chirality (Gardner, 1979) and "clues are beginning to emerge that connect chirality on different levels". Thus, and as resulting from the weak nuclear Z force between electrons and nuclei, all atoms are also chiral. Consequently, the interaction that causes the helical motion does not conserve parity, and the mirror-image atom with a right-handed helical electron flow does not exist in nature (Hegstrom and Kondepudi, 1990, see I.B).

Chirality has its fundaments in the asymmetry between electron and positron; this asymmetry follows up in the hydrogen atom and reaches its full expression in the carbon asymmetry (see II.D). The basic molecules of life all have a specific handedness. They are therefore asymmetric (see I.B): its amino acids are left-handed, whereas its sugars are right-handed (see **I**). Chiral compounds which dissociate into enantiomers display a sharp difference in biologic activity. Chemists have been able

to induce a selection between two enantiomers and to develop methodologies for asymmetric syntheses initiated from prochiral center (Mosher, 1971, in Morrison, 1983-1985; see Oppolzer, 1987 and Holmstedt *et al.,* 1989). Chiral auxiliaries have been produced around asymmetric centers using organo-copper reagents. New bondings have thus been obtained with the concourse of highly stereo reactions in compounds such as diverse drugs (R(+)-S(−) thalidomide, etc.), pheromones, and perfumes (Oppolzer, 1987).

III. MACROMOLECULAR POLARITIES

A. Free Macromolecules

1. a) *Deoxyribonucleic acid (DNA)*

a[1] *Structure.* As noticed in **I** (Fig. 5) the two polynucleotide strands of the DNA double helix have opposite polarities and transcription only occurs from the sense strand (+) in the 5'→3' direction.

The bipolar pattern of the DNA double helix has important consequences on DNA recombination processes which involve restriction enzymes (Arber, 1974; Nathans and Smith, 1975). The recognition sequence for representatives of these site-specific endonucleases such as *Eco*RI and *Hind*III is a palindrome, i.e. a sequence of six inverted repeat base pairs showing a twofold rotational symmetry. The inverted polarity of the two DNA strands imposes a positioning of the cleavage sites outside the axis of palindromic symmetry. The ensuing asymmetric cutting produces single-stranded ends containing four bases of complementary sequences.

Seemingly, small variations in molecular structure or electrostatic potential at specific sites can make a critical difference in how the nucleic acid is organized and how it is recognized by other molecules in the intracellular environment. This is becoming increasingly clear from scanning tunnelling microscopy studies of calf thymus DNA and poly(rA)·poly(rU) which have shown that the helical pitch and periodic alternation of major and minor grooves can be visualized and reliably measured (Arscott *et al.*, 1989).

a[4] *Mutations.* Those causing variegation are due to the action of transposons, a group of genetic elements known to move from one location in the genome to another. Certain strains of *Saccharomyces cerevisiae* contain an intron endowed with the ability for transposition in the gene coding for mitochondrial RNA which is absent from the corresponding gene of other strains; most of the progeny between intron plus and intron minus are positive (Dujon *et al.*, 1974). This phenomenon, termed "polarity of recombination" by Bolotin *et al.* (1971) resembles a duplicative transposition which is characteristic for prokaryotic transposons.

As recently outlined by crystallographic structural studies of contacts in repressor-operator complexes, "positioning contacts" appear to be important conserved features within families of helix-turn-helix proteins (Pabo *et al.*, 1990).

b) *Ribonucleic acid (RNA)*

Antisense RNA molecules can selectively turn off genes and be used as antisense expression vectors to produce pigment variegations in flowers (Weintraub, 1990).

2. PROTEINS

As one of the recently described DNA-binding motifs, the zinc finger protein coordinates with a Zn^{2+} ion through paired cysteine and histidine residues along the amino-to-carboxyl protein dipole (Johnson and McKnight, 1989).

The thermodynamics of membrane-located proteins containing large (hundred of Debye units) permanent dipoles has been outlined by Schwarz (1978). Ordered water molecules can contribute directly to the properties of proteins by influencing their interaction with ligands. In their studies of atomic structures of the complexes of the L-arabinose-binding protein with sugars, Quiocho *et al.* (1989) have found that "two hydrogen-bonded water molecules in the site contribute further to tight binding of L-arabinose but create an unfavourable interaction with a methyl group of D-fucose".

5. ENZYMES

The distribution of charges within the charge-relay system (or "catalytic triad") at the active site of the serine proteinases has been further investigated. An Asp--Asn mutant in rat trypsin has been engineered by Craik *et al.* (1987). As reported by (Blow, 1990), this mutant showed that "the polarization of the histidine by the buried aspartate enhanced the reactivity of the serine". Warshel *et al.* (1989) have used the technic of computational chemistry "to estimate the effect of the charged carboxylate group and the polarized histidine on the reactivity of the serine side-chain surrounded by water".

B. AGGREGATES

2. c) *Polar viral morphopoiesis*

Packaging of bacteriophage λ DNA involves polarity of chromosome entry into the prohead (**I**, p.70) from the *Nu1* end to the *R* end (Becker and Murialdo, 1990).

IV. SUBCELLULAR POLARIZATIONS

B. Surface membranes

2. a) *Biochemical properties*

The bilayer membrane can be modelled electrically as a thin slab of non conducting material separating two aqueous solutions and thereby acts as a simple parallel-plate capacitor (Gennis, 1989). "Its dielectric constant is a measure of the polarizability of the material and the degree to which any permanent electric dipoles which may be present in the material respond to an electric field (voltage difference)".

The amphiphilic phospholipids form spontaneously well-organized bilayer structures in water which are the basic architecture of biomembrane. Evidence has been obtained with membrane model systems, which support the view that lateral proton conduction occurs at water/lipid interfaces (Tocanne and Teissié, 1990). The polarity at these interfaces in terms of dielectric constant is different of that of bulk water. This means that, "in terms of micropolarity or water molecular dipole moment, the lipid/water interface region is more than likely anisotropic both in terms of structural organization and electrical properties" (see B.2b).

As for the very low permeability of the lipid bilayer to cations as compared to anions (see Tocanne and Tessié, 1990) it is ascribed to the positive polarization potential of the surface membrane (see B.2.d) which would constitute an energy barrier against the transport of positively charged compounds across membranes.

Permeability coefficients have been determined for several kinds of small molecules. Among them, water can relatively easily penetrate the membrane bilayer. As commented by Gennis (1989) "It may seem surprising at first to learn that water can so readily penetrate the phospholipid bilayer". However, "there is no substantial water to be found inside the membrane beneath the carbonyl groups".

2. c) *Energy transduction*

In 1961, two proposals were made as to the way in which electron-transfer reactions of the cytochrome chain — the chain used in the oxidation of NADH by molecular dioxygen — could be connected to ATP formation without the intervention of chemical intermediates (Williams, 1989). Both mechanisms invoked the transduction of the energy of the oxidation/reduction reaction to a proton gradient before the gradient generates ATP. The two mechanisms, sometimes termed the delocalized (Mitchell) hypothesis and the localized (Williams) hypothesis, are very different: in the first, protons generated by oxidation appear only in aqueous phases;

even ATP is generated by an electric field acting on the ATP synthetase and not by proton flow; in the second, protons move in proteins within matrices and aqueous phase equilibrations are ignored in the development of proton gradients, in proton diffusion and in the ATP-synthesis step. To distinguish between these mechanistic possibilities, long series of experiments (Wikström, 1989) have been carried out on separate parts of the cytochrome chain, especially on the last stages of the electron-transfer reactions, those of cytochrome oxidase.

Electric currents produced by oxido-reduction reactions, also called Faraday currents, can be assayed by electrochemical methods such as those of polarography. The polarograph apparatus works with three electrodes (see Monnier *et al.*, 1979): an indicator capillary electrode on which oxido-reduction reactions occur at the surface of mercury drops, a reference electrode allowing to impose to the first one a constant potential while varying the voltage, and an auxiliary electrode insuring passage of current. Registered curves of intensity-potential of chemicals such as metal ions allow their quantitative assay. Dissolved O_2 can also be measured by the polarographic technique (Fork, 1972).

In artificial fuel cells, gases are combined electrochemically such that the exothermicity is converted directly to electrical energy and the only reaction product is water. Dyer (1990) observed gas — electrical energy conversion processes occurring whithin very thin films of gas-permeable, ionically conducting membranes of hydrated aluminium oxide, as a prototypical membrane. Both polarity and the magnitude of the voltage were unexpected. The covered inner platinum electrode was positive and the polarity of the cell could be changed in $H_2 + O_2$ mixtures only when the outer platinum catalyst was changed to a nickel catalyst. This shows the strong dependence of cell polarity on the metals used and their sequence, suggesting that "different electrochemical kinetics might establish the polarity observed" (Dyer, 1990).

2. d) *Electric potentials*

Many possible factors can contribute to the amount of electrical work to move a charge through a membrane (Gennis, 1989): a) associated work with dielectric constant; b) internal dipole potential by orientation of the dipoles at the membrane surface resulting in a positive potential in the center of the phosphatidylcholine bilayer; c) surface potential which, in most biomembranes, is negatively charged, usually due to the presence of acidic, anionic phospholipids; the electric potential at the shear plane which is the plane defining what migrates in the electric field is called the zeta potential (McLaughlin, 1977); it someway controls the electrophoretic mobility of charged vesicles (electrokinetic effects); d) transmembrane potential which is defined as the difference in the electric potentials of the two bulk aqueous phases separated by the membrane. The asymmetric charge distribution generates

transmembrane potentials which are usually negative inside and can be measured with fluorescence polarity methods using probes such as merocyanine or anilinonaphthalene.

The membrane surface potential (ΔV) is the sum of an electrical term (Ψo) and a dipolar or "polarization" term (ΔVp) which exhibits high positive values (about 300 to 500 mV). The variously oriented and rotating strong dipoles of lipid polar heads would contribute to the surface polarization potential and this view (Tocanne and Teissié, 1990) has been correlated with the concept of "molecular electrometer" as developed by Seelig *et al.* (1987) on the ground of ^{2}H-NMR experiments using parameters such as the deuterium quadrupole splitting.

In fungi, marked changes in the membrane potential detected by [^{3}H]tetraphenylphosphonium (TPP^{+}) uptake rate have been caused by illumination of dark-grown mycelium of *Trichoderma viride*. An initial hyperpolarization of the plasma membrane was found to be accompanied by a rise in the intracellular ATP concentration and by changes in the intracellular level of cyclic AMP (Gresik *et al.*, 1988).

In higher plants, blue light is known to activate the electrogenic proton pump to hyperpolarize the plasmalemma (Assmann *et al.*, 1985 and Shimazaki *et al.*, 1986). Plasma membrane hyperpolarization caused by auxin (IAA), accompanied by short time oscillations in the electric potential of corn coleoptile cells, is paralleled by cytosolic pH drops as well as changes in Ca^{2+} activity (Felle, 1989). Moreover, the activity of the plant plasma membrane enzyme NADH oxidase which transfers the electrons from NADH to oxygen in the absence of added electron acceptors has been linked to membrane polarization (Novak and Ivankina, 1983). In Conjugatophycean green algae photoreception, a tetrapolar gradient of phytochrome created by light perception is achieved by the dichroitic orientation of plasma membrane-bound phytochrome molecules; blue-light also appears to mediate a tetrapolar gradient of the sensor pigment proper mediating tetrapolar actin anchorage sites on the plasmalemma (Grolig and Wagner, 1988).

Gating and ion selectivity of calcium channels have been further studied by electrophysiological experiments. Subtypes of calcium channels have been classified according to their voltage threshold for activation and by their inactivation characteristics (Wray *et al.*, 1989). Current dependence of channel gating has been tentatively ascribed to the formation of dipoles along the trajectories of ion movement that exist during dipole relaxation time (Kostyuk *et al.*, 1989). This new approach would assume that "ion transition through the open channel produces local displacements of charged molecular groups lining the wall of its steric region". During the process, the frequency of ion transitions would increase drastically and become comparable with frequency of dipole relaxation (Kostyuk *et al.*, 1989).

Release of Ca^{2+} from the sarcoplasmic reticulum (SR) following depolarization of transverse tubules (T-tubules) triggers contraction of the skeletal muscle. The foot

structure of the SR is part of a molecular bridge which spans a short gap between the T-tubules and the terminal cisternae of the SR. Large cytoplasmic extensions of the molecule evidently attach to the dihydropyridine receptor complex in the T-tubules (Agnew, 1989). There is also evidence that the dihydropyridine receptor in the T-tubule membrane of skeletal muscle functions not only as slow calcium channel but also as an essential component of coupling, probably as the voltage sensor (Takeshima *et al.*, 1989). A model of the structure of the dihydropyridine-sensitive calcium channel has been proposed (Catterall *et al.*, 1989) in analogy with current models of the structure of voltage sensitive sodium channels.

Chloride (Cl^-) channels (normal and pathological) were activated by patch excision which caused large membrane depolarization. This allowed Welsch *et al.* (1989) "to use depolarization as a "tool" to determine if a Cl^- channel was present in a patch". Active chloride transport can be light-driven by retinal proteins. These bacterio- or halorhodopsins function as inward-directed electrogenic pumps for Cl^- ions (Zimányi and Lanyi, 1989). Parallely, these pumps transport protons out of the cell interior, thereby generating an inside-negative membrane potential.

Opening and closing of chloride channels studied in the electric ray *Torpedo californica* are unequally timed. This asymmetric electric conduction increases with transmembrane electrochemical gradient for the chloride ion thus demonstrating that the channel-gating process is not at thermodynamic equilibrium (Richard and Miller, 1990).

2. e) *Action potentials*

They are not only generated in animals (see **I**) but also in fungi, algae and higher plants in response to light, heat, cold, chemicals, electrical stimulus, and wounding as reviewed by Pickard (1973) and Simons (1981). Davies (1987) considered action potentials as multifunctional signals in plants and proposed a unifying hypothesis to explain apparently disparate wound responses. Action potentials could also be a unifying factor to explain the involvement of an interaction between Ca^{2+} flux and auxin transport in the role of gravity in geotropisms (De la Fuente, 1984, also VIII.A.2.c[4]).

Cell electrophysiology and membrane transport in plants have been recently reviewed by Bentrup (1989) who stated that "the evergreen question of the role of Ca^{2+} during the characean action potential will remain elusive as long as the characean plasmalemma is not routinely accessible to patch clamp technics". In the *Characeae,* depolarization occurs by diffusive Cl^--efflux and repolarization by diffusive K^+-efflux (Köhler *et al.*, 1986; Gradmann, 1989).

The role of K^+ in the mechanisms of action potentials has been further analyzed in the green alga *Eremosphaera viridis* by Köhler *et al.* (1985, 1986) who showed that it is caused by a transient opening of a K^+ channel which is not gated by the membrane potential.

In animals, action potentials experimentally evoked by electrical activity can suppress neurite elongation and growth cone motility (Cohan and Katter, 1986) and thereby may influence structure and connectivity within the nervous system (see also VI.A.2.i).

Following electrical activity in excitable cells, there is an increase in intracellular Ca^{2+} concentration. Silver *et al.* (1990) also report that clustering of L-type Ca^{2+} channels causes intracellular Ca^{2+} hotspots at the neural growth cone. Enzymes with a micromolar requirement for Ca^{2+} at the hotspots are therefore activated by the ensuing depolarization. The role of voltage-dependent calcium influx in controlling nerve cell outgrowth remains puzzling because "also raised intracellular Ca^{2+} concentration triggers outgrowth of the growth cone margin, neurite elongation requires low intracellular Ca^{2+} concentration". According to Silver *et al.* (1990), the fact that "electrical activity can selectively raise intracellular Ca^{2+} concentration in the growth cone, leaving neurite calcium concentration low would resolve this paradox".

C. Endomembranar and vesicular systems

1. Endoplasmic reticulum

In the endomembranar sorting process, proteins destined for transfer are sequestered within membrane vesicles that bud off from a donor organelle and then fuse with the appropriate acceptor organelle. Vesicle fusion in several distinct branches of this complex distribution network as well as transfer of vesicles between the rough endoplasmic reticulum (ER) and the Golgi complex require the same cytosolic protein, a tetrameric, *N*-ethylmaleimide-sensitive protein (NEM) called NSF (Beckers *et al.*, 1989). Such transfer requires ATP and is inhibited by NEM or the monoclonal antibody against NSF. NSF is required in a late, calcium-dependent transfer step; this step is most likely the fusion step. Surprisingly, the deduced protein of cloned and sequenced NSF product showed sequence similarity with the product of a yeast gene *(SEC18)* previously shown by Schekman and Novick (1982) to control the transfer of vesicles between the rough endoplasmic reticulum and the Golgi complex; more recent studies suggested it has a function in endocytosis (Riezman, 1985). These results raise the possibility that "fusions between different organelles derived from the rough endoplasmic reticulum may all be catalyzed by the same set of proteins" (Schatz, 1989).

2. Golgi apparatus

This compact structure colocalizes with the microtubule organizing center (MTOC) in a perinuclear region of fibroblasts. Intact interphase microtubules but

not microfilaments appear to be required for this specific location of the Golgi apparatus. This has been demonstrated by the scattering of Golgi elements after treatment with the microtubule depolymerizing drug nocodazole, and by the subsequent reclustering of the Golgi elements when nocodazole is removed (Ho *et al.*, 1989). A protein may be involved in linking the Golgi apparatus to the microtubule network and the MTOC in vivo (Allan and Kreis, 1986). A fungal antibiotic, brefeldin A, produces a reversal of traffic polarity i.e. a rearrangement of Golgi elements into the ER, thereby inducing a secretion block (Bosshart *et al.*, 1990). Such "violation of the one-way system" has been further discussed by Armstrong and Warren (1990).

D. Organelles

3. Chloroplasts and phototransducing membranes

Most of the chloroplast proteins are imported from the cytosol and polarly directed into six different compartments (Smeekens *et al.*, 1990). Two sorting systems are involved in this import and intraorganellar transport of nuclear-encoded protoplast proteins. Additional sorting informations located at N- termini are contained in thylakoid lumen proteins. The information present in transit peptides, decoded by the chloroplast import machinery, is not yet known.

The electron transfer reactions in photosystem II take place within the so-called reaction center grouping numerous antenna pigment molecules (chlorophyll, etc.) as well as organic ions and charged atoms (manganese, calcium, etc.). The stepwise transfer of electrons through this reaction center succeeds in pulling far apart the mutually attractive positive and negative charges. The task of the photosystem II is thus to act as a tiny capacitor, storing energy by separating and stabilizing positive and negative charges on either side of the thylakoid membrane (Rutherford, 1989). The water-splitting reaction produces four protons and four electrons released simultaneously with O_2 in that water-oxidizing clock which is a cyclic mechanism of four states (Gowindjee and Coleman, 1990).

E. Cytoskeletal components

That the cytoskeleton is someway involved in plants intracellular movements, perception mechanism and transmission effects has again been emphasized by Hensel (1989b) who concluded that "the function of the cytoskeleton is to generate and maintain cell polarity".

As for fungal cells, they have been comprehensively surveyed in 1987 and 1989 by Hohl.

1-2. Microfilaments (actin-myosin)

Both actin and myosin filaments have definite polarities and well-ordered structures (see **I**). Actin filaments can move in opposite directions on tracks of myosin heads. They always move foreward but never backward reversing the polarity of the movement. According to Toyoshima *et al.* (1989) "The direction of movement is therefore determined by the polarity of the actin filament".

Myosin heads can form reverse chevrons and, when tethered in a single thick filament of a mutated *Drosophila* flight-muscle sarcomere, can bind with opposite rigor crossbridge angles to flanking thin filaments, which are apparently of opposite polarities (Reedy *et al.,* 1989).

The driving force for the rearrangements of the actin cytoskeleton in cell motility, division and differentiation is provided by actin-binding proteins. The addition of actin subunits to the barbed end of actin filaments and the nucleation of polymerizing actin *in vitro* are controlled by capping protein. Recent experiments suggest that capping protein regulates polar distribution *in vivo* of actin filaments. The actin cytoskeleton is disrupted in yeast capping protein mutants, indicating that "the asymmetric distribution of actin in budding yeast (see VI.A.1.a[2] in **I**) depends on the proper functioning of several actin-binding proteins with apparently different functions" (Amatruda *et al.,* 1990).

The uniform angle and conformation of myosin subfragment 1 (S1) bound to actin filaments (F-actin) "attest to the precise alignment and stereospecificity of the binding of these two contractile proteins. Because actin filaments are polar, myosin heads must swing or rotate about the head-tail junction in order to bind" (Reedy *et al.,* 1989). Adams and Pollard (1989) have shown for the first time that the single-headed myosins called myosin-I can bind directly to NaOH-extracted membranes isolated from *Acanthamoeba* and to vesicles of pure lipids with an affinity sufficient for extensive binding in the cell. Membrane-bound myosin-I may provide a mechanism for many cellular movements previously thought to involve filamentous myosin-II (see V, in **I**) and for the specification of sites of cell surface growth (Drubin *et al.,* 1990).

For a general review about cytoskeleton microfilaments, see Kristen (1987).

1-3. Microfilaments-microtubules (actin-tubulin)

In the cortex of the giant coenocytic green alga *Caulerpa,* amyloplasts are transported along microtubular strands as shown by the fact that both microtubule- and dynein-specific inhibitors block movements of these organelles. In contrast, chloroplast movement is blocked by cytochalasin but not by colchicine thereby showing that immobilization and movement of chloroplasts are dependent on intact microfilaments of actin but not on microtubules (Menzel and Elsner-Menzel, 1989).

F. NUCLEI AND MITOTIC FIGURES

2. Polewards chromosome movement

The bipolar attachment of chromosomes to the spindle occurs well before all the chromosomes congregate metaphasically. In the normal functioning of the mitotic spindle most of its growth and disassembly take place at the end of the microtubule away from the pole. All microtubules have the same polarity and the fibers behave differently depending on the structure in the spindle to which they bind. Most important as microtubule-organizing center is the centrosome which serves as a seed to start microtubule polymerization; thereby it defines their polarity. That polarity, or asymmetry, is crucial to the functioning of microtubules (see I) by at least two of its functional consequences: at the ends it causes the (+) end to add and lose subunits faster than the (−) end; along the surface it influences the orientation with which proteins will bind to the microtubule surface (McIntosh and McDonald, 1989).

The molecules involved in the mechanical forces moving polewards chromosomes begin to be unraveled (Vale and Goldstein, 1990). Among such mitotic motors there are kinesin motors and perhaps the newly discovered dynamin motor (Shpetner and Vallee, 1989) which forms cross-bridges and induces ATP-dependent sliding between antiparallel microtubules *in vitro* (McIntosh and Koonce, 1989). Kinesin is a microtubule-interactive, force-generating ATPase acting as a plus-end motor in intracellular transport of vesicles along microtubules (Vale, 1987, and others, see in **I**). The inherent asymmetry of the polymer (actin or tubulin) and the motor is necessary for the unidirectional movement of the motor along the polymer. It is toward the barbed (or +) end of the actin filament that myosin motors such as myosin I (single ellipsoidal head) move.

A superfamily of kinesin motors acting in fungal nuclear fusion and division has now been described in *Saccharomyces cerevisiae* (Meluh and Rose, 1990) and in *Aspergillus nidulans* (Enos and Morris, 1990). Such kinesin motors bear either round or rectangle heads at the end of the α-helical coiled coils. Short single-headed kinesins analogous to myosin I, kinetochore-specific kinesins, and perhaps kinesins may also be expected to be involved in morphogen or RNA transport as force-producing proteins (Vale and Goldstein, 1990).

V. POLAR CELL MOVEMENTS

B.1. *Cilia-flagella*

In the green unicellular alga *Chlamydomonas,* a component of contractile flagella roots is the centrosome-associated phosphoprotein centrin. This type of structural organization contributes to define its cell polarity through cell axiation (Fig. 1, in Salisbury, 1989).

2. *Gliding movements*

Bacterial gliding motility appears to be dependent on the establishment of transmembrane potential and any depolarization (*not* depolymerization as wrongly written in **I** p. 132) by protonophores such as 2,4-DNP or CCCP results in a cessation of motility.

3. *Amoeboid motion (transient polarity)*

Both the single headed myosin I and the double headed myosin II are mechanochemical enzymes which generate force through the hydrolysis of ATP when complexed with F-actin.

Fukui *et al.* (1989) show by immunofluorescence microscopy that non-filamentous myosin-I occurs at the leading edges of the lamellipodial projections of migrating *Dictyostelium* amoebae, which are devoid of myosin II, whereas filamentous myosin II is concentrated in the posterior zone of the cells. The authors suggested on the basis of these locations of the two forms of myosin and their known biochemical and biophysical properties that "actomyosin I may contribute to the forces that cause extension at the leading edge of a motile cell, while the contraction of actomyosin II at the rear squeezes the cell mass forward. Myosin I isoenzymes might have similar roles in metazoan cells, for example at the leading edges of neuronal growth cones, and in the extension of lamellipodia and pseudopodia of leukocytes, macrophages and fibroblasts." These observations suggest that "actomyosin I-dependent force-generating activity occurs at the leading edge (as in pseudopodia extension) and that actomyosin II-dependent force-generating activity occurs at the trailing end of a migrating *Dictyostelium* amoeba (causing the cell mass to move forwards)". This could explain "how myosin II-minus mutants can form smaller-than-normal pseudopodia at a relatively normal rate. Membrane-bound *Acanthamoeba* myosin I can generate force against actin cables however, and both *Acanthamoeba* and *Dictyostelium* myosin I will crosslink actin filaments and generate force between crosslinked filaments".

None of Fukui *et al.* (1989) observations is compatible with the participation either of other processes in amoeboid movement, such as membrane flow or the remodelling of the actin matrix, or of myosin I and myosin II in other motile activities. The significance of Fukui's team results is that they show the presence in the leading edge of a migrating cell of myosin I, which in conjunction with F-actin is known to be capable of producing force and movement.

To explain the rearward movements of membrane proteins in locomoting polymorphonuclear leukocytes, the experimentally best supported model implies the cytoskeleton (see **I**, pp. 133-137). The retrograde lipid flow hypothesis has been proposed by Bretscher (1984) as an alternative explanation for the rearward movements of membrane proteins. However, recently used techniques of low-light-level fluorescence microscopy and digital image-processing of photobleached images disprove that lipid flow model (Lee *et al.*, 1990). By further implicating cytoskeleton in proteins movements, they also validate the conclusion of Sheetz *et al.* (1989) that such a membrane flow in the leading edge of amoeboid cells does not drive rearward movements of membrane glycoproteins.

About the motor of amoeboid motion, there is much evidence linking actin-based system to the generation of motile structures in the cell (Bray and Vasiliev, 1989). Nevertheless, a mutant of *Dictyostelium discoideum* deficient in α-actinin and in which movements are unimpaired has been obtained by Gerisch's group (Wallraff *et al.*, 1986; Schleicher *et al.*, 1988). "Motile life without myosin" also exists as shown by mutants of *D. discoideum* that lack normal myosin-II (Knecht and Loomis, 1987; De Lozanne and Spudich, 1987, see **I**, p. 134). Since, André *et al.* (1989) have described a strain of this slime mold lacking severin (actin-filament fragmenting protein) even though still able to move. A relative interpretation of these findings is that "there is an extensive overlapping redundancy in the activity of actin-binding proteins *in vitro* and more than one way to crosslink, fragment or even to move actin filaments" (Bray and Vasiliev, 1989). There is analogy between the behavior of such parallely distributed processor of the locomotive cytoskeleton of *Dictyostelium* amoebae and of the cytoskeletal network intervening at yeast budding (see VI.A.1.a[2]).

VI. POLAR CELL GROWTH

A.1. Monopolar Outgrowth (emergence)

In our present state of knowledge, cytoplasmic *microtubules* are dispensable for bud outgrowth (see **I**) but required for specific, single or double budding of yeast cells or fungal spores to direct their mono- or dipolar axiation toward the site(s) of bud formation. By contrast, polarly localized actin *microfilaments* appear to be an absolute requirement for the budding processes.

a[2] *Yeast budding*

The cortical actin cytoskeleton seems to specify sites of growth of the yeast cell surface (Adams and Pringle, 1984, see **I**; Novick and Botstein, 1985). An actin-binding protein (ABP1p) might be involved in the spatial organization of cell surface growth and the identification of C-terminal protein domains suggests that such domains might serve to bring together signal transduction proteins and their targets or regulators, or both, in the membrane cytoskeleton (Drubin *et al.*, 1990).

The cytoskeletal network in the budding yeast cell *(Saccharomyces cerevisiae)* behaves as a parallely distributed processor, as suggested by the finding of a protein (SPA2) associated with actively growing regions of the cell surface (Snyder, 1989). Such polarization of the growth process is disturbed in mutant cells displaying an inability to stop growing under nutrient-limiting conditions which often results in multiple budding (multipolar growth, see **I**, p. 187).

b[1] *Fungal spores*

In the germinating spores of *Mucor rouxii* the change in growth pattern from spherical to polarized correlates with the degree of DNA methylation and this, in turn, may be controlled by polyamine levels. The establishment of the polarized phase of growth in *M. rouxii* probably occurs through the regulation of the genes involved in the synthesis of products necessary for apical growth of the hyphae (Cano *et al.*, 1988).

c) *Dimorphism*

Quite recently, Crombie *et al.* (1990) have shown that the sites of budding and germ tube formation on yeast cells of *Candida albicans* were polarized preferentially towards the cathode. Buds were found to be less polarized than germ tubes at any given applied voltage. Moreover, polarization of germ tubes was biphasic.

2. Tip growth

b) *Fungal hyphae*

In the models of hyphal tip growth, electric current does not always enter the growing end (*Allomyces* hypha drives an outward protonic current, see Youatt *et al.*, 1988 in **I**). As recently commented by Gow (1989) "Most of the evidence suggesting that ionic currents are involved in establishing and maintaining polar growth is essentially correlative, and it is not yet clear whether the current is a cause or consequence of polarity". However, Gow leaves open the possibility that "Cytoplasmic proton and calcium-ion gradients and fixed-charged gradients resulting from asymmetric transport of calcium into a cell may be involved in localizing growth". The same conclusions have recently been reached about differentiation at egg germinations of brown and red algae (Quatrano and Kropf, 1989; Waaland, 1989; see VII.C.3.a).

In hyphal tips of the oomycete *Saprolegnia ferax,* Heath and Kaminskyj (1989) observed that "all the organelles and the microtubules are non uniformly distributed, each showing a characteristic longitudinal gradient starting at a different point behind the tip". A few microtubules can reach the extreme tip but they were more abundant sub-apically. The authors concluded that "the correlated patterns of organelle and cytoskeleton organization from this and previous work show that neither the microtubules nor the detected arrays of actin are sufficient to account for most organelle arrangements".

The role of microtubules at the onset and maintenance of polarized growth of hyphae is still unclear. Intact microtubular tracks are required to initiate dominant, monopolar outgrowth from macroconidia of *Neurospora crassa* (Caesar *et al.*, 1988, see in **I**). However, further elongation of hyphae deprived of microtubules can still occur contortionally, with a damped polarity (Howard and Aist, 1980, see **I**).

Germlings of the bean rust fungus *Uromyces appendiculatus* treated with the microtubule-binding drug griseofulvin continued polarized apical growth even though showing changes in the morphology of their apical and subapical regions (Hoch *et al.*, 1987).

i) *Animal neurites*

A major question in developmental neurobiology is how developing nerve cells accurately extend processes to establish connections with their target cells (see Lasek and Black, 1988). This unsolved problem of polarized growth involves "both the nature of cues for growth cone guidance and also the question of how growth cones survey their environment for cues and respond by altering their direction of migration" (Bentley and Toroian-Raymond, 1986, see I). According to Lamoureux *et al.* (1989) "there is also controversy over whether axonal elongation is the result of a pulling growth cone and the role of tension in axonal elongation".

Earlier in this decade, the consensus was that axons or neurites elongated from tension generated by forward motility of the growth cone (Landis, 1983; Letourneau, 1982). It was presumed that contractile filopodia were the source of the tension moving the growth cone (Bray, 1982; Trinkaus, 1985). But this view was challenged by experiments showing that neurites elongate, albeit abnormally, in the presence of cytochalasin, which inhibits growth cone and filopodial movements (Marsh and Letourneau, 1984).

Bentley and Toroian-Raymond (1986) also reported an examination of the migration of pioneer growth cones deprived of filopodia by culture in agents which disrupt actin microfilaments. Under these conditions, axons continue to extend but a large percentage of growth cones are highly disoriented. Their results indicate that filopodia are not necessary for axonal elongation *in vivo* but that they are important for correctly oriented growth cone steering.

Additionally, high resolution, video-enhanced observations of growth cone activity argue against filopodial shortening as a source of tension, suggesting instead that an extrusion of cytoplasm rather than a pulling process, is the key event in neurite elongation (Goldberg and Burmeister, 1986; Bray, 1986; Aletta and Greene, 1988, ref. in Lamoureux *et al.*, 1989). Studies of slow axonal transport (Lasek, 1986) indicate that much slower cytoskeletal pushing underlies axonal elongation and direct measurements of neurite force as a function of growth cone advance show that they are linearly related and accompanied by apparent neurite growth (Lamoureux *et al.* (1989). No increase in force occurs in neurites whose growth cone fails to advance.

According to Mitchison and Kirschner (1988) there are three phases of axonal development: an actin based-system in which the leading edge becomes orientated, a consolidation phase in which filopodial microtubules become stabilized in their direction of future growth and a conversion phase to stable microtubules bundled within the axonal tube. The protein factor tau stimulates the conversion phase. However, tau expression is insufficient to induce polarity but tau antisense oligonucleotides can inhibit neurite polarity (Kosik and Finch, 1987).

Pulse-labelling studies performed both in mature nerve and in cell culture provided most of our knowledge of the axonal transport of cytoskeletal proteins. In 1975, Ochs has put forward his unitary hypothesis of axonal transport according to which proteins achieve different transport rates by having different affinities for a single moving vector. Tubulin and actin molecules are the essential components of the axonal cytoskeleton and considered by some (Black and Lasek, 1980) as a static complex travelling down the axon, a view challenged by others (ref. in Okabe and Hirokawa, 1990) who observed a gradual recovery of photobleached zones rather than their movement or spreading along the axon, both in neurons injected with fluorescein-labelled tubulin and actin. Therefore, these cytoskeletal components can be considered as "dynamic structures that continue to assemble along the length of the axon" (Okabe and Hirokawa, 1990).

In most recent and interesting experiments, Schnell and Schwab (1990) have shown that axonal regeneration and elongation in the rat spinal cord can be produced by the neutralization by monoclonal antibodies of myelin-associated neurite growth inhibitors.

VII. POLARIZED CELL DIFFERENTIATION

B. APICAL DIFFERENTIATIONS

1. *Monopolar patterns*

a) *Fungal exosporulation:* a^2 *Sporangia*

A unique capability of excised segments of sporangiophores of the terrestrial mold *Phycomyces* is to regenerate new sporangiophores with sporangia (Götze, 1918). The excised segments in the sporangiophore preferentially regenerate at the apical end. In addition to this segmental polarity, there is a polarity of the whole sporangiophore. Moreover, the fact that "polarity is not destroyed by acropetal or basipetal centrifugation seems to indicate that the plasma membrane or the cell wall (see also proposal for algal axiation in C.3.a) plays a crucial role in the polarity". Galland and Ootaki (1987) conclude from their comprehensive review that the molecular basis for this polarity is still obscure, and one of the challenging problems in *Phycomyces* differentiation remains to discover what molecules constitute the actual gradient and where are they located?

The tip of the growing zone of the sporangiophores of *Phycomyces* (Bergman *et al.,* 1969) is the site where the gravitropic bending occurs (Sachs, 1879, in Shropshire and Lafay, 1987, see VIII.A.2.c^4).

a^3 *Basidiospores*

Basidia of *Coprinus cinereus* continue differentiation when explanted to water agar and vegetative hyphal tips monopolarly elongate from the four apical sites of the basidium expected to produce sterigmata (Chiu and Moore, 1990).

C. APICO-BASAL DIFFERENTIATIONS

3. a) *Algal eggs (rhizoid-thallic poles)*

In model systems of early embryogenesis of the Fucales, the site of inward current precedes and accurately predicts the site of rhizoid outgrowth (see **I**) and the polar axis can be oriented by external vectors (light, etc.) and two unequal cells result from the first division. Experiments with inhibitors (i.e. the cytochalasins) clearly implicate microfilaments in the process of axis fixation. Moreover, such polarization of two-celled embryo cannot occur in absence of a cell wall, demonstrating that the

presence of this cellular component is an absolute requirement for axis fixation. From these results, Quatrano and Kropf (1989) derive their actual working hypothesis that "axis fixation involves transmembrane bridges at the presumptive rhizoid pole, from the cell wall to the microfilament cytoskeleton".

Using repair shoot cells and rhizoids of the red alga *Griffithsia,* Waaland (1989) tested Jaffe's hypothesis (1968, 1979, see **I**) that transcellular currents are responsible for establishing and maintaining sites of localized secretion and growth. However, in repair shoot cells, the inflowing current continued even when the cell repair hormone rhodomorphin was withdrawn and elongation stopped. Thus, in *Griffithsia* "transcellular currents *per se* do not appear to control localized organelle accumulation and localized growth".

6. *Higher animal cells*

b) *Epithelia (apical-basolateral poles)*

The apical and basolateral, macroscopic domains of polarized epithelial cells are mostly large, morphologically distinct regions of the cell surface which are separated by proteinous barriers.

The rapid diffusion and equilibration of lipophilic NH_3 across cell membranes and the accumulation of NH_4^+ seem to be governed by pH differences between compartments. Kikeri *et al.* (1989) reported that renal tubule cells from the medullary thick ascending limb of Henle have an apical membrane which is not only virtually impermeable to NH_3, but is also highly permeable to NH_4^+. They proposed a model which would explain how this renal epithelium can mediate vectorial movement of NH_4^+ between compartments of equal pH.

A hierarchy of sorting information with multiple sorting signals — apical and basolateral — present in different domains of a given plasma membrane protein has been suggested from the evidence that covalently attached glycosyl-phosphatidylinositol (GPI) acts as a "dominant" apical targeting signal. Polarized epithelial protein sorting might therefore rely on glycolipids (Lisanti and Rodriguez-Boulan, 1990).

VIII. MORPHOGENETIC POLARIZATIONS

A. PLANTS

2. *Organismic polarities*

a) Mushrooms

These higher fungi grow upwards and should be responsive to the gravitational field. The problem will be to find the gravity sensor and the way its signals are interpreted (also for the model mold *Phycomyces,* see below).

c[4]) *Polar auxin transport and tropic curvatures*

Bioelectric gradients along axial organs demonstrate morphological and physiological polarity in higher plants (Fensom, 1959; Scott, 1967; Zatsepina and Tsaplev, 1980; Goldsworthy, 1986). This electric polarity probably controls the distribution of phytohormones (Clark, 1937). Changing the bioelectric gradients by an external electric field has various consequences on plant growth and development (Lund *et al.,* 1947; Cholodny, 1956; Jaffe and Nuccitelli, 1977; Ellis and Turner, 1978; Medvedev and Markova, 1990).

In studies of gravity-dependent plant responses provided by the special conditions of spaceflights, interfering accelerations are relatively small (below 10^{-3} g) and termed "microgravity" (see Hensel, 1989a).

Plant morphogenesis in general does not appear to be considerably disturbed by microgravity, as shown by the polar differentiation of anise callus cultures into somatic embryos (Theimer *et al.,* 1986). Compared to ground controls the distribution of the amyloplasts is shifted towards the proximal pole in statocytes of space grown roots (ref. in Hensel, 1986). This polarity of statocytes does not require the continuous action of gravity but develops also at microgravity. In statocytes of lentil roots differentiated in microgravity, the nucleus was preferentially located toward the gravity center of the cell (Perbal and Driss-Ecole, 1989). Polar differentiation of statocytes was also disturbed but only at the level of endoplasmic reticulum (ER) in seedlings of *Zea mays* launched from earth after germination, while those germinated at microgravity had aggregated ER in root statocytes (Moore *et al.,* 1987).

By comparison, the normally negatively gravitropic sporangiophores of the terrestrial mold *Phycomyces* (see VII.B.1a[2]) become disoriented when cultivated aboard an orbiting spacecraft (Parfyonov *et al.,* 1979). The nature of the gravity receptor is still unknown (Shropshire and Lafay, 1987).

As previously suggested, statocytes polarity depends on a genetically prepatterned program (Sievers *et al.*, 1976). Since, agravitropic mutants of roots have been discovered (see Scott, 1990). Such mutants exhibit morphological and physiological abnormalities which suggest that they are unable to respond to the plant growth hormone auxin, indole-3-acetic acid (Hicks *et al.*, 1989). The root cap plays a role in root geotropism (Pilet, 1978) and its removal can also lead to an agravitropism (Moore *et al.*, 1990). Gravity could thus induce a change in cellular structure which somehow generates a chemical and/or electrical signal in the cap.

The starch statolith hypothesis attempts to explain gravity perception in plants. Starchless (phosphoglucomutase deficient) mutants recently produced in *Arabidopsis thaliania* (Caspar and Pickard, 1989) showed a lower response to gravity. The authors concluded that a full complement of starch is necessary for full gravitropic sensitivity (Kiss *et al.*, 1989). However, these mutants can still sense gravity also more slowly and less accurately. According to Bandurski (1990) "if an organism has a dense and heavy statolith then it will use the statolith to provide a very accurate and rapid gravity sensor. If however it does not have such a dense body then the organism uses some more subtle gravity sensing apparatus". Bandurski's guess is then "that the plant uses its own bioelectric fields as a sensor". With his collaborators he had developed a working theory postulating that "the perception of the gravitational stimulus involves a perturbation of the plant's bioelectric field" and that the transduction of the stimulus involves a hormone-transport voltage-gating mechanism (Bandurski *et al.*, 1986).

In the provoking suggestions concluding his recent review on "Plant Movements and the Cytoskeleton", Hensel (1989b) suggests that the cytoskeleton has a general function to generate and maintain polarity of root cap statocytes but that the cytoskeleton is "indirectly involved in perception by generating and maintaining a structural polarity of statocytes". Interestingly "it maintains domains of ion pumps/channels and/or hormone receptors/channels in the plasma membrane". The cortical part of the cytoskeleton would be directly involved in mechanotransduction of statolith weight into shear forces, thus triggering a plasma membrane response.

B. Animals

Polar axiation in the eggs and embryos as well as the mechanisms underlying these processes in annelids, arthropods, amphibia and mammals are further discussed in a symposium on "Cellular Basis of Morphogenesis" published by Wolpert in 1989.

2. BIAXIAL PATTERNS: i) *Mammals*

Homologous gene clusters have been recently compared in insects and vertebrates. Specific homologues of *Antennapedia* (*Antp*)-like homeobox genes in *Drosophila* (see VIII.B.2d, in **I**) have been characterized as *Hox* complexes in vertebrates (Duboule *et al.*, 1986). Corresponding murine genes and insect complexes show the same relative boundary of the expression along the antero-posterior (A/P) axis of the developing embryo (Akam, 1989). A model for the mouse forelimb budding has been proposed by Dollé *et al.* (1989) that accounts for the establishment of the expression of the *Hox-5* domain in relation to the existence of a morphogen released by the zone of polarizing activity.

3. TRIAXIAL PATTERNS (left-right polarities)

Handedness is a fundamental quality already appreciated by D'Arcy Thompson (1942, see **I**).

a) *Helical bacteria*

The twist model of the lytic-deficient mutations of *Bacillus subtilis* has recently reactivated the handedness principle (Mendelson and Thwaites, 1989). Growth of these lytic-deficient mutants does not result in increased numbers of individual bacteria but in long thread-like clones which may have an unusual double-helical morphology. These double-helical threads fold repeatedly to form helical, multicellular "macrofibres" ("macrobes") that, according to Galloway (1990) are structurally analogous to twisted textile yarns. A macrobe is therefore an amplifier of the cell wall structure-determining features of the individual cells and therefore has a helical structure.

On the basis of screw sense, some strains are left-handed, others right. Others again are "conditional" mutants — they may be either left or right, and the degree of twist can vary continuously between left-handed and right-handed extremes depending on environmental factors, such as temperature (Galloway, 1990). Right-hand clones are produced at lower temperatures, left-hand at higher ones (Mendelson *et al.*, 1984). It seems that a protein is needed for left-handed structures but not right-handed.

e) *Molluscs*

Interestingly, a same asymmetric behaviour as in bacteria is seen in the early development of snails: right-handedness in *Lymnaea peregra* needs a protein, left-

handedness apparently does not (see **I**). In the interplay between molecular self-assembly into helicoidal structures and mechanical reorientation due to growth forces (Neville, 1985; Galloway, 1990), a central role has been suggested to microtubules in the formation of helical patterns (Lloyd, 1984).

EPILOGUE (complement to pp. 271-273 in **I**)

The predictor question — What is life? — asked by the brilliant physicist Erwin Schrödinger in 1945 has since been partially answered by the cracking of the enigma of the genetic code. However, it still leaves open the question of "How does this one-dimensional code specify a three-dimensional organism?", a question relevant of topobiology (Edelman, 1988). At this epigenetic level, organizational principles of inanimate objects appear to be still valid even though complexified for animate ones. Preeminent among such universal principles is polarity emerged from the primary asymmetries of particulate matter (see I.B) and multi-expanded into the numerous biopolarities.

To bridge genetics and epigenetics still remains the great question of how genes control the transduction of the intrinsic molecular polarities into those cellular and organismic biopolarities? The bridge starts to be completed at the cellular level with the recent unravelling of genes controlling polarity of cytoskeletal macromolecules such as actin, myosin and tubulins (see IV.E), themselves someway related to known cell positioning as examplified by our *Allomyces* "sexual dipoles" (Plate **I**). However, the link remains elusive at the organismic level where some types of interaction should intervene between macromolecular polarities and DNA-controlled directional (head or foot in the Hydra model) morphogenetic gradients.

I renew my gratefulness to ARIANE FEHR for her trustful technical help.

REFERENCES

ADAMS, R. J. and T. D. POLLARD (1989). Binding of myosin I to membrane lipids. *Nature* 340: 565-568.

AGNEW, W. S. (1989). Excitation-contraction coupling: cloning of the SR foot. *Nature* 339: 422-423.

AKAM, M. (1989). *Hox* and HOM: homologous gene clusters in insects and vertebrates. *Cell* 57: 347-349.

ALLAN, V. J. and T. E. KREIS (1986). A microtubule-binding protein associated with membranes of the Golgi apparatus. *J. Cell Biol.* 103: 2229-2239.

AMATRUDA, J. F., J. F. CANNON, K. TATCHELL, C. HUG and J. A. COOPER (1990). Disruption of the actin cytoskeleton in yeast capping protein mutants. *Nature* 344: 352-354.

ANDRÉ, E., M. BRINK, G. GERISCH, G. ISENBERG, A. NOEGEL, M. SCHLEICHER, J. E. SEGALL and E. WALLRAFF (1989). A *Dictyostelium* mutant deficient in severin, an F-actin fragmenting protein, shows normal motility and chemotaxis. *J. Cell Biol.* 108: 985-995.

ARBER, W. (1974). DNA modification and restriction. *Prog. Nucl. Acid Res. Mol. Biol.* 14: 1-37.

ARMSTRONG, J. and G. WARREN (1990). Membranes: violating the one-way system. *Nature* 344: 383-385.

ARSCOTT, P. A., G. LEE, V.A. BLOOMFIELD and D. F. EVANS (1989). Scanning tunnelling microscopy of Z-DNA. *Nature* 339: 484-486.

ASSMANN, S., L. SIMONCINI and J. I. SCHROEDER (1985). Blue light activates electrogenic ion pumping in guard cell protoplasts of *Vicia faba*. *Nature* 318: 285-287.

BANDURSKI, R. S. (1990). Oral communication, Feb. 1990.

BANDURSKI, R. S., A. SCHULZE and W. DOMAGALSKI (1986). Possible effects of organelle charge and density on cell metabolism. *Adv. Space Res.* 6(12): 47-54.

BARNES, P., J. L. FINNEY, J. D. NICHOLAS and J. E. QUINN (1979). Cooperative effects in simulated water. *Nature* 282: 459-464.

BECKER, A. and H. MURIALDO (1990). Bacteriophage λ DNA: the beginning of the end. *J. Bacteriol.* 172: 2819-2824.

BECKERS, C. J. M., M. R. BLOCK, B. S. GLICK, J. E. ROTHMAN and W. E. BALCH (1989). Vesicular transport between the endoplasmic reticulum and the Golgi stack requires the NEM-sensitive fusion protein. *Nature* 339: 397-398.

BENTRUP, F.-W. (1989). Cell electrophysiology and membrane transport. *Progr. Bot.* 51: 70-79.

BERGMAN, K. *et al.* (1969). *Phycomyces. Bacteriol. Rev.* 33: 99-157.

BLACK, M. M. and R. J. LASEK (1980). Slow components of axonal transport: two cytoskeletal networks. *J. Cell Biol.* 86: 616-623.

BLOW, D. (1990). More of the catalytic triad. *Nature* 343: 694-695.

BOLOTIN, M., D. COEN, J. DEUTSCH, B. DUJON, P. NETTER, E. PETROCHILO and P. P. SLONIMSKI (1971). La recombinaison des mitochondries chez *Saccharomyces cerevisiae*. *Bull. Inst. Pasteur* 69: 215-239.

BOSSHART, H., P. STRAEHL, B. BERGER and E. G. BERGER (1990). Brefeldin A induces a microtubule-directed backflow of Golgi to ER membranes. *Experientia* 46: S2 3.

BOUCHIAT, A.-M. and L. POTTIER (1984). An atomic preference between left and right. *Sci. Amer.* 250(6): 76-85.

BRACK, A. *et al.*, interrogés par E. Noël (1989). La Symétrie Aujourd'hui. Sciences, éd. du Seuil, Paris. 238 pp.

BRAY, D. (1982). Filopodial contraction and growth cone guidance. In *Cell Behaviour*. Pp. 299-317. R. Bellair, A. Curtis and G. Dunn (eds). Cambridge University Press.

BRAY, D. and J. VASILIEV (1989). Networks from mutants. *Nature* 338: 203-204.

BRETSCHER, M. S. (1984). Endocytosis: relation to capping and cell locomotion. *Science* 224: 681-686.

BRODSKY, M. H. (1990). Progress in gallium arsenide semiconductors. *Sci. Amer.* 262(2): 56-63.

CACERES, A. and K. S. KOSIK (1990). Inhibition of neurite polarity by tau antisense oligonucleotides in primary cerebellar neurons. *Nature* 343: 461-463.

CAILLOIS, R. (1973). La Dissymétrie. Gallimard, Paris.

CANO, C., L. HERRERA-ESTRELLA and J. RUIZ-HERRERA (1988). DNA methylation and polyamines in regulation of development of the fungus *Mucor rouxii. J. Bacteriol.* 170: 5946-5948.

CASPAR, T. and B. G. PICKARD (1989). Gravitropism in a starchless mutant of *Arabidopsis. Planta* 177: 185-197.

CATTERALL, W.A., M. J. SEAGAR, M. TAKAHASHI and K. NUNOKI (1989). Molecular properties of dihydropyridine-sensitive calcium channels. In *Calcium Channels: Structure and Function.* D. W.-Wray, R. I. Norman and P. Hess (eds). *Ann. N.Y. Acad. Sci.* 560: 1-14.

CHIU, S. W. and D. MOORE (1990). Sporulation in *Coprinus cinereus*: use of an *in vitro* assay to establish the major landmarks in differentiation. *Mycol. Res.* 94: 249-253.

CHOLODNY, N. G. (1956). Selected works in 3 volumes. Vol. 1. Materials for Plant Electrophysiology. Pp. 358-374. Kiev Acad. Sci. URSS.

CLARK, W. G. (1937). Electrical polarity and auxin transport. *Plant Physiol.* 12: 409-440.

CLEGG, J. S. (1982). Alternative views on the role of water in cell function. In *Biophysics of Water.* Pp. 365-383. F. F. Franks and S. Mathias (eds), John Wiley and Sons, Chichester, New York. 400 pp.

CLINE, D. B. (1988). Beyond truth and beauty: a fourth family of particles. *Sci. Amer.* 259(2): 42-49.

COHAN, C. S. and S. B. KATTER (1986). Suppression of neurite elongation and growth cone motility by electrical activity. *Science* 232: 1638-1640.

CRAIK, C. S., S. ROCZNIAK, C. LARGMAN and W. J. RUTTER (1987). The catalytic role of the active site of aspartic acid serine proteases. *Science* 237: 909-913.

CROMBIE, T., N. A. R. GOW and G. W. GOODAY (1990). Influence of applied electrical fields on yeast and hyphal growth of *Candida albicans. J. Gen. Microbiol.* 136: 311-317.

DAVIES, E. (1987). Action potentials as multifunctional signals in plants: a unifying hypothesis to explain apparently disparate wound responses. *Plant Cell Environ.* 10: 623-631.

DOLLÉ, P., J.-C. IZPISUA-BELMONTE, H. FALKENSTEIN, A. RENUCCI and D. DUBOULE (1989). Coordinate expression of the murine *Hox-5* complex homeobox-containing genes during limb pattern formation. *Nature* 342: 767-772.

DROST-HANSEN, W. and J. L. SINGLETON (1989). Liquid asset. How the exotic properties of cell water enhance life. *The Sciences* Sept./Oct.: 38-42.

DRUBIN, D. G., J. MULHOLLAND, Z. ZHU and D. BOTSTEIN (1990). Homology of a yeast actin-binding protein to signal transduction proteins and myosin-I. *Nature* 343: 288-290.

DUBOULE, D., A. BARON, P. MÄHL and B. GALLIOT (1986). A new homeo-box is present in overlapping cosmid clones which define the mouse *HOX*-1 locus. *EMBO J.* 5: 1973-1980.

DUJON, B., P. P. SLONIMSKI and L. WEILL (1974). Mitochondrial genetics IX: A model for recombination and segregation of mitochondrial genomes in *Saccharomyces cerevisiae. Genetics* 78: 415-435.

DYER, C. K. (1990). A novel thin-film electrochemical device for energy conversion. *Nature* 343: 547-548.

EDELMAN, G. M. (1988). Topobiology. An Introduction to Molecular Embryology. Basic Books, Inc., Publishers, New York. 240 pp.

ELLIS, H. W. and E. R. TURNER (1978). The effect of electricity on plant growth. *Sci. Prog.* 65: 395-407.

ELLIS, J. (1990). Deep resonance of CP violation. *Nature* 344: 197-198.

ENOS, A. P. and N. R. MORRIS (1990). Mutation of a gene that encodes a kinesin-like protein blocks nuclear division in *A. nidulans*. *Cell* 60: 1019-1027.

ERNST, R. R., G. BODENHAUSEN and A. WOKAUN (1987). Principles of Nuclear Magnetic Resonance in One and Two Dimensions. Oxford Scientific Publ. Clarendon Press.

ERRERA, J. (1928). Polarisation Diélectrique. Presses Universitaires de France.

—— (1935). Le Moment Electrique en Chimie (2 vol.). Hermann, Paris.

FARLEY, F. W. and G. M. MCCLELLAND (1990). Orientational dielectric relaxation of collisionless molecules. *Science* 247: 1572-1575.

FELLE, H. (1989). pH as a second messenger in plants. In *Second Messengers in Plant Growth and Development*. Plant Biology, vol.6, pp. 145-166. W. F. Boss and D. J. Morré (eds), Alan R. Liss, New York. 348 pp.

FENSOM, D. S. (1959). The bio-electrical potentials of plants and their functional significance. 3. The production of continuous potentials across membranes in plant tissue by the circulation of the hydrogen ion. *Can. J. Bot.* 37: 1003-1026.

FIELD, M. J. and R. W. RICHARDSON (1989). *Arch. rational Mech. Anal.* 105: 91-94; cited by I. Stewart (1989). Symmetry breakthrough. *Nature* 341: 389-390.

FINNEY, J.L. (1982). Towards a molecular picture of liquid water. In *Biophysics of Water*. Pp. 73-95. F.F. Franks and S. Mathias (eds), John Wiley and Sons, Chichester, New York. 400 pp.

FORK, D. C. (1972). Oxygen electrode. *Methods Enzymol.* 24B: 113-122.

FOUKAL, P. V. (1990). The variable sun. *Sci. Amer.* 262(2): 26-33.

FUENTE, de la, R.K. (1984). Role of calcium in the polar secretion of indoleacetic acid. *Plant Physiol.* 76: 342-346.

FUKUI, Y., T. J. LYNCH, H. BRZESKA and E. D. KORN (1989). Myosin I is located at the leading edges of locomoting *Dictyostelium* amoebae. *Nature* 341: 328-331.

GALLAND, P. and T. OOTAKI (1987). Differentiation and cytology. In *Phycomyces*. Pp. 281-316. E. Cerdá-Olmedo and E. D. Lipson (eds). Cold Spring Harbor Laboratory. 430 pp.

GALLOWAY, J. (1990). Putting a twist in the tale. *Nature* 343: 513-514.

GARDNER, M. (1979). The Ambidextrous Universe: Mirror Asymmetry and Time-Reversed Worlds. Second and Uptdated Edition. Charles Scribner's Sons.

GENNIS, R. B. (1989). Biomembranes. Molecular Structure and Function. Springer-Verlag, New York, Berlin. 533 pp.

GOLDSWORTHY, A. (1986). The electrical compass of plants. *New Sci.* 109: 22-23.

GÖTZE, H. (1918). *In* Galland and Ootaki, 1987.

GOVINDJEE and W. J. COLEMAN (1990). How plants make oxygen. *Sci. Amer.* 262(2): 42-51.

GOW, N. A. R. (1989). Circulating ionic currents in micro-organisms. *Adv. Microb. Physiol.* 30: 89-123.

GRADMANN, D. (1989). Electrogenic chloride transport in Algae. In *Bicarbonate, Chloride, and Proton Transport Systems*. J. H. Durham and M. A. Hardy (eds). *Ann. N.Y. Acad. Sci.* 574: 20-29.

GRESIK, M., N. KOLAROVA and V. FARKAS (1988). Membrane potential, ATP, and cyclic AMP changes induced by light in *Trichoderma viride*. *Exper. Mycol.* 12: 295-301.

GROLIG, F. and G. WAGNER. (1988). Light-dependent chloroplast reorientation in *Mougeotia* and *Mesotaenium:* Biased by pigment-regulated plasmalemma anchorage sites to actin filaments? *Bot. Acta* 101: 2-6.

HARGITTAI, I. and M. HARGITTAI (1986). Symmetry Through the Eyes of a Chemist. VCH. 458 pp.

HEATH, I.B. and S.G.W. KAMINSKYJ (1989). The organization of tip-growth-related organelles and microtubules revealed by quantitative analysis of freeze-substituted Oomycete hyphae. *J. Cell Sci.* 93: 41-52.

HEGSTROM, R.A. and D.K. KONDEPUDI (1990). The handedness of the Universe. *Sci. Amer.* 262 (1): 98-105.

HENSEL, W. (1986). Cytodifferentiation of polar plant cells. Use of anti-microtubular agents during the differentiation of statocytes from cress roots *(Lepidium sativum L.)*. *Planta* 169: 293-303.

—— (1989*a*). Physiology of movements in space experiments. *Progr. Bot.* 50: 158-162.

—— (1989*b*). Plant movements and the cytoskeleton. *Progr. Bot.* 51: 165-172.

HICKS, G.R., D.L. RAYLE and T.L. LOMAX (1989). The *Diageotropica* mutant of tomato lacks high specific activity auxin binding sites. *Science* 245: 52-54.

HO, W.C., V.J. ALLAN, G. VAN MEER, E.C. BERGER and T.E. KREIS (1989). Reclustering of scattered Golgi elements occurs along microtubules. *Eur. J. Cell Biol.* 48: 250-263.

HOCH, H.C., B.E. TUCKER and R.C. STAPLES (1987). An intact microtubule cytoskeleton is necessary for mediation of the signal for cell differentiation in *Uromyces*. *Eur. J. Cell Biol.* 45: 209-218.

HOHL, H.R. (1987). Cytology and morphogenesis of fungal cells. *Progr. Bot.* 49: 13-28.

—— (1989). Cytology and morphogenesis of fungal cells. *Progr. Bot.* 51: 1-20.

HOLLENBECK, P.J. (1990). Cytoskeleton on the move. *Nature* 343: 408-409.

HOLMSTEDT, B., H. FRANK and B. TESTA (eds) (1989). Chirality and Biological Activity. John Wiley and Sons, New York. 300 pp.

JAEGER, F.M. (1925). Principe de Symétrie. Gauthier-Villars.

JAFFE, L.F. and R. NUCCITELLI (1977). Electrical control of development. *Ann. Rev. Biophys. Bioeng.* 6: 445-476.

JOHNSON, P.F. and S.L. McKNIGHT (1989). Eukaryotic transcriptional regulatory proteins. *Ann. Rev. Biochem.* 58: 799-839.

KIKERI, D., A. SUN, M.L. ZEIDEL and S.C. HEBERT (1989). Cell membranes impermeable to NH_3. *Nature* 339: 478-480.

KISS, J.Z., R. HERTEL and F.D. SACK (1989). Amyloplasts are necessary for full gravitropic sensitivity in roots of *Arabidopsis thaliana*. *Planta* 177: 198-206.

KNECHT, D.A. and W.F. LOOMIS (1987). Antisense RNA inactivation of myosin heavy chain gene expression in *Dictyostelium discoideum*. *Science* 236: 1081-1086.

KÖHLER, K., W. STEIGNER, W. SIMONIS and W. URBACH. (1985). Potassium channels in *Eremosphaera viridis*. I. Influence of cations and pH on resting membrane potential and on an action potential-like response. *Planta* 166: 490-499.

KÖHLER, K., W. STEIGNER, J. KOLBOWSKI, U.P. HANSEN, W. SIMONIS and W. URBACH (1986). Potassium channels in *Eremosphaera viridis*. II. Current- and voltage-clamp experiments. *Planta* 167: 66-75.

KOSIK, K.S. and E.A. FINCH (1987). MAP2 and tau segregate into dendritic and axonal domains after the elaboration of morphologically distinct neurites: an immunocytochemichal study of cultured rat cerebrum. *J. Neurosci.* 7: 3142-3153.

KOSTYUK, P., N. AKAIKE, Y. OSIPCHUK, A. SAVCHENKO and Y. SHUBA (1989). Gating and permeation of different types of Ca channels. In *Calcium Channels: Structure and Function*. D.W. Wray, R.I. Norman and P. Hess (eds). *Ann. N.Y. Acad. Sci.* 560: 63-79.

KRISTEN, U. (1987). General and molecular cytology: the cytoskeleton: microfilaments. *Progr. Bot.* 49: 1-12.

LAMOUREUX, P., R.E. BUXBAUM and S.R. HEIDEMANN (1989). Direct evidence that growh cone pull. *Nature* 340: 159-162.

LANGMUIR, I. (1932). Cited by Peratt, 1990.

LANDIS, S. C. (1983). Neuronal growth cones. *Ann. Rev. Physiol.* 45: 567-580.

LASEK, R. J. (1986). Polymer sliding in axons. *J. Cell. Sci.* (suppl.) 5: 161-179.

LASEK, R. J. and M. M. BLACK (eds) (1988). Intrinsic Determinants of Neuronal Form and Function. Neurology and Neurobiology, vol. 37. Alan R. Liss, New York. 591 pp.

LEE, J., M. GUSTAFSSON, K.-E. MAGNUSSON and K. JACOBSON (1990). The direction of membrane lipid flow in locomoting polymorphonuclear leukocytes. *Science* 247: 1229-1233.

LENK, R., M. BONZON and H. GREPPIN (1980). Dynamically oriented biological water as studied by NMR. *Chem. Phys. Lett.* 76: 175-177.

LETOURNEAU, P. C. (1982). Nerve fiber growth and its regulation by extrinsic factors. In *Neuronal Development.* Pp. 213-254. N. C. Spitzer (ed.). Plenum, New York.

LINDEN, E. (1990). Can we really understand matter? *Time,* April 16, p. 41.

LISANTI, M. P. and E. RODRIGUEZ-BOULAN (1990). Glycophospholipid membrane anchoring provides clues to the mechanism of protein sorting in polarized epithelial cells. *Trends Biochem. Sci.* 15: 113-118.

LLOYD, C. W. (1984). Toward a dynamic helical model for the influence of microtubules on wall patterns in plants. *Inter. Rev. Cytol.* 86: 1-54.

LUCKEN, E. A. C. (1969). Nuclear Quadrupole Constants. Academic Press, London, New York. 360 pp.

LUND, E. J., R. I. MAHAN and A. H. HANSZEN (1947). Reversible total inhibition of polar growth in the root by an applied electric current and the nature of this control. In *Bioelectric Fields and Growth.* Pp. 186-197. E.J. Lund. (ed.). Univ. Press Austin, Tx., U.S.A.

MARSH, L. and P. C. LETOURNEAU (1984). Growth of neurites without filipodial or lamellipodial activity in the presence of cytochalasin B. *J. Cell Biol.* 99: 2061-2067.

MCINTOSH, J. R. and M. P. KOONCE (1989). Mitosis. *Science* 246: 622-628.

MCINTOSH, J. R. and K. L. MCDONALD (1989). The mitotic spindle. *Sci. Amer.* 261(4): 26-34.

MCLAUGHLIN, S. (1977). Electrostatic potentials at membrane-solution interfaces. *Current Topics in Membranes and Transport* 9: 71-144.

MEDVEDEV, S. S. and I. V. MARKOVA (1990). How can the electrical polarity of axial organs regulate plant growth and IAA transport? *Physiol. Plant.* 78: 38-42.

MELUH, P. B. and M. D. ROSE (1990). *KAR3,* a kinesin-related gene required for yeast nuclear fusion. *Cell* 60: 1029-1041.

MENDELSON, N. H. and J. J. THWAITES (1989). Do forces and the physical nature of cellular materials govern biological processes? *Comments Theor. Biol.* 1: 217-236.

MENDELSON, N. H., D. FAVRE and J. J. THWAITES (1984). Twisted states of *Bacillus subtilis* macrofibers reflect structural states of the cell wall. *Proc. Natn. Acad. Sci. U.S.A.* 81: 3562-3566.

MENZEL, D. and C. ELSNER-MENZEL (1989). Actin-based chloroplast rearrangements in the cortex of the giant coenocytic green alga *Caulerpa. Protoplasma* 150: 1-8.

MITCHISON, T. and M. KIRSCHNER (1988). Cytoskeletal dynamics and nerve growth. *Neuron* 1: 761-772.

MONNIER, D., W. HAERDI, J. BUFFLE and Y. RUSCONI (1979). Chimie Analytique. Georg, Genève. 293 pp.

MOORE, R., C. E. MCCLELEN, W. M. FONDREN and C. L. WANG (1987). Influence of microgravity on root-cap regeneration and the structure of columella cells in *Zea mays. Am. J. Bot.* 74: 218-223.

MOORE, R., M. L. EVANS and W. M. FONDREN (1990). Inducing gravitropic curvature of primary roots of *Zea mays* cv ageotropic. *Plant Physiol.* 92: 310-315.

NATHANS, D. and H. O. SMITH (1975). Restriction endonucleases in the analysis and restructuring of DNA molecules. *Ann. Rev. Biochem.* 44: 273-293.

NEVILLE, A. C. (1985). Molecular and mechanical aspects of helicoidal development in plant cell walls. *BioEssays* 3: 4-8.

NICOLLE, J. (1950). La Symétrie et ses Applications. Albin Michel, Paris.

NOVAK, V. A. and N. G. IVANKINA (1983). Influence of nitro blue tetrazolium on the membrane potential and ion transport in water thyme. *Sov. Plant. Physiol.* 30: 845-853. (English translation).

NOVICK, P. and D. BOTSTEIN (1985). Phenotypic analysis of temperature-sensitive yeast actin mutants. *Cell* 40: 405-416.

OCHS, S. (1975). In *Recent Advances in Myology*. Pp. 189-194. W. G. Bradley *et al.* (eds). Excerpta Medica, Amsterdam. 578 pp.

OKABE, S. and N. HIROKAWA (1990). Turnover of fluorescently labelled tubulin and actin in the axon. *Nature* 343: 479-482.

OPPOLZER, W. (1987). Camphor derivatives as chiral auxiliaries in asymmetric synthesis. *Tetrahedron* 43: 1969-2004.

OSIEWACZ, H. D. and U. HEINEN (1989). Recombination of mobile genetic elements from plants and cyanobacteria. *Progr. Bot.* 50: 174-197.

PABO, C. O., A. K. AGGARWAL, S. R. JORDAN, L. J. BEAMER, U. R. OBEYSEKARE and S. C. HARRISON (1990). Conserved residues make similar contacts in two repressor-operator complexes. *Science* 247: 1210-1213.

PARFYONOV, G. P. *et al.* (1979). Biological investigations aboard biosatellite cosmos-782. *Acta Astronaut.* 6: 1235.

PARISELLE, H. (1936). Polarimétrie et Chimie. Gauthier-Villars. Paris

PERATT, A. L. (1990). Not with a bang. *The Sciences* Jan./Feb.: 24-32.

PERBAL, G. and D. DRISS-ECOLE (1989). Polarity of statocytes in lentil seedling roots grown in space. (Spacelab D1 Mission). *Physiol. Plant.* 75: 518-524.

PICKARD, B. G. (1973). Action potentials in higher plants. *Bot. Rev.* 39: 172-201.

PILET, P.-E. (1978). The role of the cap in the geotropism of roots exposed to light. *Z. Pflanzenphysiol.* 89: 411-426.

PONT, V. and R. PEZET (1990). Relation between the chemical structure and the biological activity of hydroxystilbenes against *Botrytis cinerea*. *J. Phytopathol.* (in press).

POOL, R. (1989). Chaos in a hydrogen atom. *Science* 243: 894.

PRICE, A. H. (1969). In *Dielectric Properties and Molecular Behavior*. Pp. 191-231. N.E. Hill (ed.). Van Nostrand Reinhold, New York.

QUATRANO, R. F. and D. L. KROPF (1989). Polarization in *Fucus* (Phaeophyceae) zygotes: investigations of the role of calcium, microfilaments and cell wall. In *Algae as Experimental Systems*. Plant Biology, vol. 7, pp. 111-119. A. W. Coleman, L. J. Goff and J. R. Stein-Taylor (eds). Alan R. Liss, New York. 333 pp.

QUIOCHO, F. A., D. K. WILSON and N. K. VYAS (1989). Substrate specificity and affinity of a protein modulated by bound water molecules. *Nature* 340: 404 and 732.

REEDY, M. C., C. BEALL and E. FYRBERG (1989). Formation of reverse rigor chevrons by myosin heads. *Nature* 339: 481-483.

REES, M. J. (1990). "Dead quasars" in nearby galaxies? *Science* 247: 817-823.

RICHARD, E. A. and C. MILLER (1990). Steady-state coupling of ion-channel conformation to a transmembrane ion gradient. *Science* 247: 1208-1210.

RIEZMAN, H. (1985). Endocytosis in yeast: Several of the yeast secretory mutants are defective in endocytosis. *Cell* 40: 1001-1009.

ROBERTS, R. G. (1990). Quark spins open to question. *Nature* 344: 708-709.

RUTHERFORD, A.W. (1989). Photosystem II, the water-splitting enzyme. *Trends Biochem. Sci.* 14: 227-232.

SAENGER, W. (1987). Structure and dynamics of water surrounding biomolecules. *Ann. Rev. Biophys. Biophys. Chem.* 16: 93-114.

SALISBURY, J. L. (1989). Algal centrin: calcium-sensitive contractile organelles. In *Algae as Experimental Systems.* Plant Biolology, vol. 7, pp. 19-37. A. W. Coleman, L. J. Goff and J. R. Stein-Taylor (eds). Alan R. Liss, New York. 333 pp.

SCHATZ, G. (1989). Cell biology: biological cold fusion. *Nature* 339: 336.

SCHEKMAN, R. and P. NOVICK (1982). The secretory process and yeast cell surface assembly. In *The Molecular Biology of the Yeast Saccharomyces cerevisiae:* metabolism and gene expression. Pp. 361-393. J. N. Strathern, E. W. Jones and J. R. Broach (eds). Cold Spring Harbor Laboratory, New York.

SCHLEICHER, M., A. NOEGEL, T. SCHWARZ, E. WALLRAFF, M. BRINK, J. FAIX, G. GERISCH and G. ISENBERG (1988). A *Dictyostelium* mutant with severe defects in α-actinin: its characterization using cDNA probes and monoclonal antibodies. *J. Cell Sci.* 90: 59-71.

SCHNELL, L. and M. E. SCHWAB (1990). Axonal regeneration in the rat spinal cord produced by an antibody against myelin-associated neurite growth inhibitors. *Nature* 343: 269-272.

SCHRÖDINGER, E. (1945). What is life? The Physical Aspect of the Living Cell. Cambridge University Press; Macmillan, New York.

SCHWARZ, G. (1978). On the physico-chemical basis of voltage-dependent molecular gating mechanisms in biological membranes. *J. Membrane Biol.* 43: 127-148.

SCOTT, B. I. H. (1967). Electrical fields in plants. *Ann. Rev. Plant Physiol.* 18: 409-418.

SCOTT, I.M. (1990). Plant hormone response mutants. *Physiol. Plant.* 78: 147-152.

SCOTT, J. F. and C. A. PAZ DE ARAUJO (1989). Ferroelectric memories. *Science* 246: 1400-1405.

SEELIG, J., P. M. MACDONALD and P. G. SCHERER (1987). Phospholipid head groups as sensors of electric charges in membranes. *Biochemistry* 26: 7535-7541.

SHEETZ, M. P., S. TURNEY, H. QIAN and E. L. ELSON (1989). Nanometre-level analysis demonstrates that lipid flow does not drive membrane glycoprotein movements. *Nature* 340: 284-288.

SHIMAZAKI, K., M. IINO and E. ZEIGER (1986). Blue light-dependent proton extrusion by guard-cell protoplasts of *Vicia faba. Nature* 319: 324-326.

SHPETNER, H. S. and R. B. VALLEE (1989). Identification of dynamin, a novel mechanochemical enzyme that mediates interactions between microtubules. *Cell* 59: 421-432.

SHROPSHIRE, W. Jr. and J.-F. LAFAY (1987). Sporangiophore and mycelial responses to stimuli other than light. In *Phycomyces.* Pp. 127-154. E. Cerdá-Olmedo and E. D. Lipson (eds). Cold Spring Harbor Laboratory. 430 pp.

SIEVERS, A., D. VOLKMANN, W. HENSEL, V. SOBICK and W. BRIEGLEB (1976). Cell polarity in root statocytes in spite of simulated weightlessness. *Naturwiss.* 43: 343.

SIMONS, P. J. (1981). The role of electricity in plant movements. *New Phytol.* 87: 11-37.

SILVER, R. A., A. G. LAMB and S. R. BOLSOVER (1990). Calcium hotspots caused by L-channel clustering promote morphological changes in neuronal growth cones. *Nature* 343: 751-754.

SKLIFKIN, M. A. (1980). The significance of charge transfer interactions in biology. In *Molecular Interactions,* vol. 2, pp. 271-304. H. Ratajezak and W. J. Orville-Thomas (eds). John Wiley and Sons, New York.

SMEEKENS, S., P. WEISBEEK and C. ROBINSON (1990). Protein transport into and within chloroplasts. *Trends Biochem. Sci.* 15: 73-76.

SMITH, K.F. *et al.* (1990). A search for the electric dipole moment of the neutron. *Phys. Lett.* B 234: 191-196.

SNYDER, M. (1989). The *SPA2* protein of yeast localizes to sites of cell growth. *J. Cell Biol.* 108: 1419-1429.

TAKESHIMA, H., S. NISHIMURA, T. MATSUMOTO, H. ISHIDA, K. KANGAWA, N. MINAMINO, H. MATSUO, M. UEDA, M. HANAOKA, T. HIROSE and S. NUMA (1989). Primary structure and expression from complementary DNA of skeletal muscle ryanodine receptor. *Nature* 339: 439-445.

THEIMER, R., R.A. KUDIELKA and I. RÖSCH (1986). Induction of somatic embryogenesis in anise in microgravity. *Naturwiss.* 73: 442-443.

THOMAS, J.O. and G.C. FARRINGTON (1982). Protonic beta-aluminas: model systems for proton transfer in biological processes. In *Biophysics of Water.* Pp. 215-217. F.F. Franks and S. Mathias (eds), John Wiley and Sons, Chichester, New York. 400 pp.

TOCANNE, J.-F. and J. TEISSIÉ (1990). Ionization of phospholipids and phospholipid-supported interfacial lateral diffusion of protons in membrane model systems. *Biochim. Biophys. Acta* 1031: 111-142.

TOYOSHIMA, Y.Y., C. TOYOSHIMA and J.A. SPUDICH (1989). Bidirectional movement of actin filaments along tracks of myosin heads. *Nature* 341: 154-156.

TRINKAUS, J.P. (1985). Further thoughts on directional cell movement during morphogenesis. *J. Neurosci Res.* 13: 1-19.

TURIAN, G. (1989). Polarity. From Dipoles to Biopolarizations. *Arch. Sci. Genève* 42: 1-323.

—— (1990). Le couple divin (bipôles de vie). *Campus* (Uni-Genève) 1: 14-15.

VALE, R.D. and L.S.B. GOLDSTEIN (1990). One motor, many tails: an expanding repertoire of force-generating enzymes. *Cell* 60: 883-885.

WAALAND, S.D. (1989). Cellular morphogenesis in the filamentous red alga *Griffithsia.* In *Algae as Experimental Systems.* Plant Biology, vol. 7, pp. 121-134. A.W. Coleman, L.J. Goff and J.R. Stein-Taylor (eds). Alan R. Liss, New York. 333 pp.

WALLRAFF, E., M. SCHLEICHER, M. MODERSITZKI, D. RIEGER, G. ISENBERG and G. GERISCH (1986). Selection of *Dictyostelium* mutants defective in cytoskeletal proteins: use of an antibody that binds to the ends of α-actinin rods. *EMBO J.* 5: 61-67.

WARSHEL, A., G. NARAY-SZABO, F. SUSSMAN and J.-K. HWANG (1989). How do serine proteases really work? *Biochemistry* 28: 3629-3637.

WEINTRAUB, H.M. (1990). Antisense RNA and DNA. *Sci. Amer.* 262(2): 34-40.

WELSH, M.J., M. LI, J.D. McCANN, J.P. CLANCY and M.P. ANDERSON (1989). Phosphorylation-dependent regulation of apical membrane chloride channels in normal and cystic fibrosis airway epithelium. In *Bicarbonate, Chloride, and Proton Transport Systems.* J.H. Durham and M.A. Hardy (eds). *Ann. N.Y. Acad. Sci.* 574: 44-51.

WEYL, H. (1952). Symmetry. Princeton University Press, New Jersey, U.S.A. 168 pp.

WIKSTRÖM, M. (1989). Identification of the electron transfers in cytochrome oxidase that are coupled to proton-pumping. *Nature* 338: 776-778.

WILLIAMS, E.R. (1988). The electrification of thunderstorms. *Sci. Amer.* 259(5): 48-65.

WILLIAMS, R.J.P. (1989). Electron transfer: Energizing protons in membranes. *Nature* 338: 709-710.

WOLPERT, L. (1989). Cellular Basis of Morphogenesis. Ciba Foundation Symposium 144. John Wiley and Sons. 280 pp.

WRAY, D.W., R.I. NORMAN and P. HESS (eds) (1989). Calcium Channels: Structure and Function. *Ann. N.Y. Acad. Sci.*, vol. 560. 475 pp.

ZATSEPINA, G. I. and J. B. TSAPLEV (1980). The nature of electric polarity in higher plants. *Biofizika* 25: 144-147 (In Russian).

ZIMÁNYI, L. and J. K. LANYI (1989). Halorhodopsin: a light-driven active chloride transport system. In *Bicarbonate, Chloride, and Proton Transport Systems.* J. H. Durham and M. A. Hardy (eds). *Ann. N.Y. Acad. Sci.* 574: 11-19.

SUBJECT INDEX

Abiotic, 46
Acetone, 39
Achiral, 45
Acidic, 40, 62, 82, 101-103, 112, 167, 168, 218, 339
  compartment, 167, 175, 185, 220
  hyaloplasm, 154
  pH, 235
  polysaccharide, 207
  protein, 154
Acidification, 101, 108, 151, 175, 186, 236
Acridine(s), 198, 199
Actin, 15, 38, 80, 81, 96, 112-118, 120, 125, 129, 130, 132-136, 139, 144, 145, 152-154, 163, 167, 168, 177, 179, 180, 187, 200, 211, 218, 325, 344-347, 349, 350, 358
  binding site, 115, 118, 344, 348
  cable(s), 118, 130, 346
  cortex, 180
  dots, 151-154
  F-, 111, 113, 114, 117, 145, 174, 346, 347
  G-, 111, 114
  G-F, 133
  microfilaments, 152, 167, 173, 174, 179, 207, 344, 348
  molecule(s), 112, 114, 350
  polymerization, 179
  translocation, 180
Actin-binding protein(s), 115, 344, 348
Actin-like filaments, 154
Actin-mediated transport, 183
Action potential(s), 87, 88, 90-94, 341, 342
Activation, 52, 60, 64, 67, 80, 92, 102, 117, 127, 145, 148, 158, 162, 189, 198, 217, 222, 232, 243, 247, 248, 250, 341
Actomyosin, 89, 133, 134, 154, 346
Adhesion, 81, 115, 134, 136, 181
Affinity, 39, 40, 42, 60, 76, 106, 114, 194, 347
Agglutinin, 79, 80
Aggregates-aggregation, 68-71, 87, 96, 118, 137, 169, 209, 226, 228, 243, 265, 337
Agravitropism, 355
Algal
  axiation-differentiation, 195, 352
  eggs-embryos, 157-159, 229, 352
  elongation, 184
  exosporulation, 195
  rhizoids, 168
  zygote, 171, 207
Algorithm, 61
Amines, 40, 41, 95
Amino acids, 40, 41, 44-46, 57, 58, 60, 66, 67, 73, 81, 86, 95, 96, 167, 168, 249, 328, 334, 337
  polar, 62
Ammonia (-ium), 68, 243, 353
Amoeboid (Amoeba), 15, 137-139, 141
  cells, 147, 347
  motion, 133-137, 346, 347
  movement, 134, 135, 346
Amphipathic, 37, 40, 63, 65, 76-78, 80
Amphitropic, 77
Ampholytes, 41
Amphoteric, 38, 41
Amyloplasts, 168, 236, 344, 354
Anaphase, 120, 125, 126
Anchorage, 63, 76, 81, 115, 153, 222, 339
Animal(s), 211, 212, 214-217, 223, 246, 250, 253, 255, 272, 325, 342, 353, 355
  cell(s), 189, 211, 223, 262, 353
  eggs-embryo 13, 211, 212, 225, 238, 325
  gradient, 217, 255
  pole, 190, 212, 217, 254, 255, 263
  regeneration, 13
Animal-vegetal (A/V)
  axis, 212, 216, 253, 254, 262
  gradient(s), 264, 265
  halves, 255

polarity, 211, 214, 216, 217, 253, 254, 262, 263, 269
Anion(s), 30, 91, 220, 339
Anisometry, 39, 70, 150, 181
Anisotropy, 24, 185, 111, 112, 333, 338
Ankyrin, 112, 221
Annihilation, 17, 21, 22
Anode, 180
Antenna, 108-111, 343
Anterio-posterior (A/P)
axis, 245, 249, 250, 252, 256, 259, 260, 265, 267-270, 356
differentiation, 228
gradients, 264
pattern(s), 240, 257
polarities, 213, 241-249, 250-266, 267-270
regeneration, 262
Anterior
pole, 213, 228, 229, 257-260, 263
segment, 256
structures, 259
tip, 243, 257
Anterograde (inward) transport, 122, 177-179
Antheridia, 174, 197
Antibiotic, 86, 151, 183, 343
Antibodies, 66, 115, 204, 220, 249, 353
Antigenes, 66, 67, 150, 243
Antimatter, 18, 19, 21, 47, 327, 328
Antiparallel, 25, 29, 49, 50, 64, 68, 86, 87, 117, 120, 345
Antiport, 82
Antisense, 58, 336, 350
Antisera, 267
Apex, 64, 129, 164, 165, 166, 169, 170, 172, 175, 180, 193-195, 197, 224, 225, 227, 232, 238, 239, 241
Apical, 13, 100, 104, 137, 169-173, 208, 218, 221, 225, 226, 231, 242, 271, 348, 352, 353
axis, 184
bud, 232
cell(s), 160, 169, 172-174, 197, 205, 209, 211, 268
differentiation(s), 192-221, 352, 353
division, 173
dome, 194
dominance, 164, 165, 231, 242
growth, 157, 162, 344, 345
meristem(s) 224, 229, 231, 238, 239
pattern(s), 189, 236
pole(s), 162, 170, 218-220, 223, 225, 248, 256, 266, 267, 272
targeting signal, 348
zone, 100, 163, 164, 168, 169, 174, 175, 231
Apical and basolateral
compartments (domains), 219, 220, 226, 353
gradients, 104, 171, 172
poles, 218, 219, 248, 352
surfaces, 220, 221
Apolar (nonpolar), 37-40, 43, 50, 55, 61, 67, 75, 97, 147, 201, 264, 266, 271, 325
cells, 14, 79, 87, 158, 160, 209, 264, 266, 271
egg, 158
growth, 149, 160
Archegonia, 174, 197
Ascospores, 155
Assembly, 57, 69, 70, 99, 111, 114, 117, 119-123, 125, 126, 132, 179, 202, 203, 219
Asymmetric
budding, 219
carbon, 32
distribution-transport, 80, 218, 339, 341, 345, 349, 350
division(s), 149, 150, 161, 189, 192, 200-202, 206, 210, 211, 222, 225, 229, 230, 252
growth, 236
septation, 190, 191, 202, 205
structure(s), 74, 82, 202
synthesis, 46, 335
Asymmetry, 13, 18, 35, 44, 46-48, 50-52, 64, 66, 74, 77, 79, 82, 100, 102, 108, 109, 112, 114, 119, 123, 132, 145, 154, 159, 173, 181, 186, 194, 200, 205, 206, 208, 210, 213, 216, 225, 230, 236, 237, 247, 266-269, 326, 327, 328, 334-336, 339, 341, 345, 356, 358
Atomic, 17-32, 325-331

ATP, 81, 83-85, 100, 104, 106-110, 114, 116, 117, 120, 122, 123, 128, 132, 135, 140, 142, 143, 160, 167, 179, 186, 192, 218, 327, 333, 338, 340, 345, 346
  pump, 106
  synthesis, 83-85, 339
ATPase, 82-85, 90, 91, 102, 106, 110, 115, 118, 121-123, 126, 128, 129, 167, 168, 220, 345
Auxin(s), 159, 160, 186, 222, 229-231, 233-238, 340, 354, 355
  transport, 229, 230, 233, 235, 341, 354
Auxospores, 147, 184
Axis-axes (axiation), 13, 21, 22, 29, 31, 32, 47, 50, 60, 64, 71, 79, 86, 104, 105, 107, 123, 130, 132, 137, 144-148, 154, 157, 165, 170, 182, 188-190, 192, 198, 200, 201, 206, 207, 213, 216, 221-224, 227, 228, 231, 233, 238, 241, 244, 246-250, 262-265, 271, 352-354, 356
  division, 209
  growth, 147, 158, 161, 165
  polarity, 148, 154, 161, 185, 192, 200, 205, 212, 213, 222, 227, 228, 233, 239, 242, 248, 262, 266, 272, 348, 354, 355
  proximal-distal, 261
Axial, 66, 133, 174, 224, 247, 249, 356
  asymmetry, 13
  development, 224
  head activator gradient, 248
  regeneration, 13
  symmetry, 64, 221, 249, 265
Axon(s), 90-92, 94, 105, 122, 123, 177-181, 349-351
  cytoskeleton, 350
  transport, 122, 177, 178, 350
Axoneme, 122
Axoplasm, 123, 179

Bacterial, 129-132, 140, 167, 181, 356
  budding, 149, 150
  cell(s), 53, 182, 190
  chromosome, 183
  division, 190
  elongation, 167, 182
  helical, 267, 356
  shape, 150, 181
  sporulation (endospores), 190, 191
Bacteriochlorophyll, 43
Bacteriorhodopsin, 109, 142
Band(s), 104, 110, 117, 130, 136, 148, 169, 172, 185, 195, 215
Barbed end(s), 114, 130, 145
Basal, 68, 122, 131, 137-139, 145, 147, 155, 160, 169-171, 193, 207, 208, 218, 225, 233, 235, 242, 244, 247, 249, 255, 256
  bodies, 104, 244-246, 256
  cell, 204, 211, 225
  compartment, 205
  permeability, 235
  pole(s), 158, 170, 181, 221, 225
  rhizoidal, 208
  zone, 163, 164, 170
Basidia, 227, 228, 352
Basidiocarp, 227
Basidiospores, 155, 194, 195, 226, 352
Basolateral, 218, 220
  cell surface, 219-221
  domain, 220
  membrane, 98, 218, 220, 221, 267
  pumps, 220
Bending, 50, 131, 168, 169, 174
Benzene, 39, 43, 67
Biaxial patterns, 250-267, 356
Bidirectional, 102, 123, 179
Bifurcation, 143
Big Bang, 17, 19, 327
Bilayer(s), 63, 75-78, 107, 333, 338, 340
Binary, 23, 26, 272, 330
  fission, 149, 150, 182, 201
Binding, 17, 24, 33, 34, 39, 50, 52, 57, 60, 64, 66-70, 77, 80, 86, 90, 93, 96, 112, 114, 123, 140, 337, 344
  protein(s), 60, 114, 337
  site, 66, 111
Bioelectric field(s), 237, 354, 355
  potentials, 166
Bioelectrochemistry, 110
Biosynthesis, 62, 73, 129, 155, 166
Biopolarity, 14, 273, 326, 358
Bipolar, 13, 22, 64, 72, 107, 113, 115-118, 124, 130, 167, 170, 173, 181-186, 195, 196, 202, 208, 209, 229, 247,

259, 271, 272, 325, 330, 348
axiation, 147, 181, 186, 192, 197, 204
budding, 184, 187
couple, 17, 21
differentiation(s), 181, 202, 204, 205, 229
field(s), 41, 222, 232, 240, 247
filaments, 116, 117
germination, 184
gradient, 200
growth, 167, 181-186, 271
mating systems, 195
mitochondrion, 107
pattern(s), 41, 195-201, 332, 336
regeneration, 251, 262
segregation, 184, 199
sexualization, 195, 196, 200
Bipolarity, 22, 41, 70, 108, 113, 116, 117, 119, 183, 185, 200, 204
Bipolarization, 70, 257, 258, 271, 272
electric, 19-22, 330
Bipolaron, 24
Blastocyst, 266, 267
Blastomere(s), 252-254, 262, 264, 266, 267
Blue light, 31, 169, 174, 209, 340
Bond(s), 24, 35, 39-41, 55, 59, 60, 62, 64-66, 68, 92, 332-335
Boson(s), 19, 24, 27, 29, 44, 327
Branching, 93, 164, 165, 169, 195, 228, 231
Brevin, 113
Bridges, 45, 70, 115, 122, 345, 353
Bristle(s), 176, 261
Bud(s), 95, 97, 101, 103, 149-154, 163, 172, 184, 187, 231-233, 239, 348
growth, 150-154
meristem, 238
polarity, 152
Budding, 102, 149-151, 153, 154, 162, 184, 187, 196, 246, 247, 342, 344, 348, 356
bacterial, 149, 150
forelimb, 265, 356
polar, 151
yeast, 150, 154, 184, 187, 326, 347, 348

Ca^{2+}, 73, 81, 88-90, 95, 106, 114, 118, 141-143, 166, 168, 169, 175, 180, 194, 209, 232, 237, 261, 340-342
channel(s), 89, 90, 175, 207, 216, 341, 342
currents, 216
gradients, 175, 262, 349
ionophore, 209, 254, 261
pump, 106
transport, 106, 342, 349
uptake, 106
Calcium, 23, 80, 88, 89, 93, 95, 102, 106, 116, 135, 139, 160, 237, 253, 254, 340-342, 349
Calcofluor, 153
Callus, 147, 239, 354
Calmodulin, 95, 116, 139, 142, 237
Cambium, 189
Cancer, 148
Capping, 80, 81, 113, 127
protein(s), 114, 344
Capsid(s), 69
Carbohydrate(s), 13, 17, 72, 75, 78, 100, 109, 355
Carbon, 38-40, 44, 60, 67, 75, 192, 248, 334
Carotene, 42, 158, 198, 199, 228
Carotenoids, 109, 161
Catalysis (-yst), 45, 56, 339
Cathode, 74, 180, 188, 348, 349
Cation(s), 23, 24, 30, 37, 38, 78, 81, 86, 90, 92, 99, 135, 143, 338
Caulonema, 172
Causal, 214, 217, 231, 255
CCl_4, 38, 39
Cell(s), 13-15, 23, 30, 34, 38, 46, 52, 62, 64, 68, 72-74, 77-81, 83, 85, 87-105, 107-109, 111-115, 117-119, 121-127, 129-154, 157, 160-166, 170-193, 196, 197, 200-226, 228-230, 232, 233, 235-241, 243-247, 249-252, 254, 257, 259, 261-268, 271, 272, 325, 326, 333, 338, 342-348, 352-354, 358
adhesion, 82
asymmetry, 205
axes, 175, 190, 271, 346
compartment(s), 191
cycle(s), 151, 153, 154, 165, 183, 197, 201, 202, 203, 229, 243, 264, 267, 270
cytoplasm, 191
differentiation, 81, 189-221, 228, 244, 245, 272, 352-354

division(s), 12, 15, 147, 148, 152, 160, 165, 169, 173, 185, 187, 190, 191, 196, 200, 201, 203, 205, 206, 210, 222, 232, 244-246, 252, 253, 268, 272
elongation, 148, 169, 182, 185, 186, 222, 238
growth, 147-188, 348-351
membrane(s), 333, 353
movement(s), 123, 129-146, 346, 347
polarity, 15, 112, 148, 154, 159, 160, 186, 190, 191, 205, 235, 248, 261, 272, 344, 346
polarization, 205, 207
pole(s), 203, 204
surface(s), 63, 80, 89, 112, 149, 150, 157, 166, 181, 184, 204, 218, 219, 220, 246, 249, 255, 333, 348-350, 353
target(s), 345
Cellulose, 64, 129, 147, 176, 185-187, 206, 211, 241, 244
Centriole(s), 124, 127, 138, 195
Centrosome(s), 120, 124, 126-128, 141, 144, 145, 151, 345, 346
Cephalon-abdomen, 215, 257, 258
CH_3Cl, 39
CH_4, 38, 39
Channel(s), 22, 66, 83, 86, 87, 90, 91, 93, 94, 110, 141, 142, 154, 167, 194, 221, 340-342, 355
gated (-ing), 83, 340, 341
ionic (H^+, K^+, Na^+, Ca^{2+}, Cl^-), 86-95, 154, 175, 180, 207, 216, 221, 341
ligand-gated, 87
polar, 90
voltage gated, 87, 88
Chaos, 17, 328
Charge(s), 18-20, 22-24, 28, 33, 35, 42-44, 51, 52, 59-62, 64, 67, 68, 71, 74, 83, 84, 86, 87, 92, 108-110, 131, 135-137, 168, 271, 272, 327-334, 337, 343
asymmetry, 271, 339
separation, 43, 343
transfer, 328, 334
Chelation, 59
Chemical communication, 149
Chemical forces, 34
Chemiosmotic theory, 82-85, 186, 102, 109, 235
Chemo-structural gradient, 197
Chemotaxis, 60, 134, 139-141, 145, 241
Chirality, 15, 19, 43-48, 50, 53, 86, 124, 268, 325-328, 334, 335, 356
Chitin, 150, 153, 154
Chitosomes, 155, 157
Chloral, 160
Chloride, 85, 341
Chloroform, 39
Chloronema(ta), 172, 209
Chlorophyll, 60, 109, 110, 211, 343
Chloroplast(s), 50, 51, 83, 103, 108-111, 129, 130, 169-172, 195, 205, 209, 229, 343, 344
Choline, 65, 92
Chromaffin granules, 102
Chromatophore, 110
Chromosome(s), 52, 55, 120, 124-126, 128, 182, 192, 201, 203, 214, 252, 272, 337, 345
Cilia, 104, 112, 114, 118, 121, 123, 130-132, 141, 145, 346
Circular, 50, 51, 71, 86, 124, 327
polarization, 45, 47, 48
Cis-, 53, 81, 89, 97-100, 102, 103, 257, 260
Cl^- (see also Chloride), 158, 341
Clathrin, 101, 102
Clay(s), 73, 74
Cleavage(s) 45, 57, 66, 101, 158, 194, 211-213, 215, 217, 218, 229, 249, 252, 253, 255, 258, 259, 262-264, 266, 268, 269, 336
CO_2, 38, 65, 109, 162, 192
Coalescence, 242
Coat, 71, 117, 202
Code, 53, 54, 57, 260, 336, 358
Coenzymes (see also NAD-NADP), CoA, 65, 103
Colchicine, 141, 160, 173, 179, 186, 206, 211, 251, 344
Coleoptile, 186, 340
Commitment, 201, 210, 249
Communication, 72, 89, 249
Compartment(s), 72, 84, 99, 102, 103, 106, 168, 205, 220, 346, 353, 355
Competence, 198
Complexity, 69, 145, 197, 226, 231
Computer(s), 23, 26, 61, 66, 146, 330, 337
Conductivity-conductance, 22-25, 86, 107,

329, 333, 338, 341
Conformation, 45, 49, 50, 70, 85-87, 89, 117, 121, 344
Conidia, 107, 155, 156, 184, 187, 188, 192, 193, 196, 349
Copper ($Cu^{+/2+}$), 23, 24, 61, 65, 66, 335
Cortex, 100, 134, 136, 138, 144, 145, 202, 210, 212, 216, 244, 263, 344, 346
Cosmic, 17, 25, 325, 327, 328, 330
Coupling, 20, 24-26, 54, 82, 86, 89, 94, 97, 102, 111, 148, 185, 223, 250, 326, 341
Crystal(s), 18, 21-24, 31, 32, 35, 37, 40, 55, 63, 64, 68, 76, 86, 110, 271, 328-333
Current(s), 22, 23, 26, 34, 45, 62, 92, 95, 120, 129, 137, 139, 142, 143, 154, 159, 161, 166-169, 194, 207, 216, 230, 235, 236, 262, 339, 341, 349, 353
  loop(s), 157, 168, 231, 272
Cyanide, 132
Cycle(s), 90, 102, 113, 133, 135, 136, 147, 154, 165, 201, 203, 330
Cyclic, 139, 179, 343
  adenosine monophosphate, 253
  cAMP, 134, 140, 141, 157, 162, 163, 240, 243, 340
  guanosine 5'-phosphate, 89
  photophosphorylation, 192
Cyclosis, 129, 162, 164
Cylindrical, 69, 71, 78, 130, 137, 147, 154-163, 165, 182, 183, 186, 221, 328
  germ tubes, 154-161
Cysteine-Cystine, 40, 41, 337
Cytochalasin(s) B, E, H, 80, 113, 145, 179, 200, 206, 207, 229, 344, 350, 352
Cytochemical gradients, 166
Cytochrome(s), 61, 66, 84, 198, 338, 339
  oxidase, 198, 339
Cytogel, 72
Cytokeratin, 111
Cytokinesis, 136, 151, 153, 154, 161, 184, 200, 208
Cytolytic, 99
Cytoplasm, 15, 54, 62, 72, 85, 89, 103, 104, 112, 122, 124, 129, 130, 136, 142, 158, 161, 164, 168, 172, 173, 176, 186, 189, 190, 194, 198, 199, 208, 210, 212-214, 217, 218, 225, 235, 236, 255, 257, 259, 264, 269, 271, 272, 350
Cytoplasmic, 15, 79-81, 88, 89, 94, 95, 100, 106, 111, 115, 123, 124, 126, 129-131, 133, 139, 141, 146, 149, 151, 152, 158, 161, 168, 169, 173, 179, 185, 189, 194, 197, 198, 200, 206, 209-214, 217, 221, 228, 229, 235, 252, 255, 261, 262, 264, 340, 349, 350
  basophilic gradient, 193
  DNA, 198
  granules, 151
  movements, 73, 129, 261
  streaming, 15, 129, 130, 137, 162, 164, 175
  zonation, 169
Cytoskeleton, 81, 111, 112, 124, 132, 138, 139, 144, 145, 158, 162, 166, 173, 174, 176, 177, 179, 180, 200, 204, 206, 213, 214, 218, 219, 254, 264, 271, 325, 343-350, 353, 355, 358
  outgrowths, 261
  protein(s), 73, 77, 95, 99, 177, 350, 356
Cytosol, 65, 72, 73, 77, 102, 111, 118, 130, 172, 177, 179, 343

Dehydrogenases, 82, 84
Deoxyribonucleic acid (DNA), 45, 49-57, 61, 64, 70, 71, 81, 155, 189-191, 197-200, 203, 259, 260, 272, 336, 337, 348, 358
  packaging, 71, 337
  polarity, 49, 336
  polymerase, 61
  positioning, 197-200
  replication, 52, 190, 203
  segregation, 191
  topology, 53
  transcription, 52-54
Depolarization, 87-92, 94, 95, 108, 141, 142, 157, 216, 221, 251, 334, 340, 341, 346
Design, 42, 69, 74
Desmin, 111
Detergent(s), 63, 76, 78, 110, 115
Determinants, 122, 215, 253

Development, 15, 27, 72, 74, 91, 147, 152, 155, 157, 160, 164, 165, 167, 169-172, 176, 189, 193, 194, 203, 204, 206, 208, 210, 212, 213, 217, 221, 222, 224-230, 232, 238, 240, 243, 244, 247, 251-255, 260, 261, 263, 264, 270, 272, 338, 356
Dielectric, 19, 34, 61, 67, 332, 338, 339
  constant, 78, 338
  polarization, 332
Dielectrophoresis, 78
Differentiation, 13, 15, 139, 181, 189-221, 223, 225, 228, 230, 231, 233, 238, 240, 243, 244, 247, 255, 256, 260, 264, 269, 352-354
  apical, 192-200
  apico-basal, 200-221
  intercalary, 190-192
Diffusion, 14, 25, 61, 76, 77, 101, 104, 154, 166, 235, 240, 272, 273, 333, 338, 354
  gradient(s), 14, 224, 228
Dimorphism, 117, 157, 161-163, 201, 203, 238, 348
Diode, 23, 330
Diploid, 184, 196, 197
Dipole(s), 13, 23, 26, 30, 33-39, 41-43, 58, 59, 61-63, 68, 75, 76, 79, 86, 87, 108, 111, 249, 250, 271, 273, 325-334, 336, 340, 343, 358
  electric, 21, 22, 33, 34, 328, 329
  field, 25, 332
  interactions, 76
  mineral, 34-38, 332, 333
  moment(s), 25, 33, 37, 39, 58, 60, 63, 76, 85-87, 89, 111, 329, 330, 332, 338
  organic, 38-43, 334
  protein, 61, 337
  water, 34-38, 332, 333
Diprotic, 41
Direction (-ality), 17, 19, 23, 25, 26, 28-33, 37, 43, 45, 49-53, 57, 58, 61, 62, 82, 86, 93, 99, 104, 106, 115-119, 121-123, 126, 129, 130, 133, 136, 140-147, 159, 160, 164, 165, 173, 174, 176, 179, 182, 185, 186, 189, 192, 197, 199, 205, 207-210, 220, 221, 224, 228, 231-234, 236, 241, 245, 249, 252, 254, 255, 261-263, 332, 344, 350, 352, 358
  division, 148, 185, 186, 200
  light, 209
  nucleation, 244
Dismutation, 66
Dissipation, 195, 197
Dissymmetry, 33, 38
Division(s) 79, 104, 120, 148, 149, 151, 160, 161, 172-174, 176, 181-183, 186, 189, 191, 192, 197, 200, 202, 203, 205, 206, 209-213, 217, 222, 224, 225, 229, 232, 245, 252, 253, 267, 268, 272, 345, 352
  nuclear, 125, 152, 205
  unequal, 182, 197, 200, 205, 209, 212, 272
Domain(s), 47, 58, 66, 67, 76, 79, 81, 103, 213, 218, 221, 254, 260, 329, 349, 353-356
Dominance, 13, 47, 144, 242
Dorsal, 263
  meristem, 231
  tissue(s), 250, 257
  products, 260
Dorso-ventral (D/V)
  axis, 256, 262
  genes, 259
  gradients, 264
  pattern(s), 256, 260
  polarities, 214, 250-266, 267-270
  structure, 173, 209
Dots, 152-154, 205
Double
  gradient(s), 190, 255
  helix, 50, 51, 56, 57, 112, 336
  strands, 62, 86
Driving force(s), 42, 43, 111, 134, 135, 147, 166, 167, 186, 230, 345, 346
Drug(s) 70, 80, 101, 121, 144, 145, 152, 188, 267, 335, 343, 349
Duality, 13, 54, 67, 108, 140, 142, 161, 166
Duplex, 52, 53
Dyad, 51
Dynamics, 46, 111, 121, 126, 127
Dynamin, 345
Dynein, 121, 123, 126, 129, 179, 344

Ecto-meso-endoderms, 213, 248, 262, 264, 266, 269, 270

Ectoplasm, 129, 133, 134, 173, 215, 261
Egg(s), 13, 14, 157, 158, 190, 201, 204, 206, 208, 210-218, 225, 241, 252-265, 268-270, 325, 349, 352, 355
  axial polarity, 213, 217, 253, 254, 355
  crescents
    grey, 255, 262, 263
    yellow-orange-red, 216, 254, 261, 262
  fertilized, 158, 159, 204, 210, 213, 215, 252, 253, 263
Electric(al), 13, 14, 21-23, 26, 33-38, 60, 70, 74, 84, 86, 87, 89, 90-93, 107, 123, 131, 132, 143, 166, 168, 174, 209, 221, 248, 271, 272, 325, 338-342
  biopolarity, 26, 107, 158, 272
  bipolarity, 13, 15, 23, 108, 136, 230, 239, 271, 354
  bipolarization, 15, 19, 22, 328
  charge(s), 13, 14, 17-22, 27, 29, 30, 34, 35, 40, 41, 61, 62, 70, 85, 87, 93, 109, 221, 271, 325, 328, 329, 343
  current(s), 26, 34, 62, 73, 74, 78, 79, 158, 159, 168, 204, 207, 209, 262, 325, 327, 339, 349
  depolarization, 89
  dipole(s), 19, 21, 23, 27, 33-36, 63, 76, 87, 137, 272, 325, 328, 330, 339
  field(s), 19, 22-24, 31-34, 36, 37, 41, 61, 62, 78, 85, 87, 110, 137, 145, 160, 167, 168, 176, 180, 188, 201, 209, 210, 239, 247, 332, 338-340, 355
  gradient, 102, 204
  moment(s), 33, 38, 39, 272, 329, 331, 332
  poles, 27, 175, 325, 333
  potential(s), 83-86, 89, 90, 106-108, 133, 142, 143, 159, 166, 170, 200, 235, 338-340
  signal(s), 87, 93, 94, 221
  stimulation, 89, 154, 341
Electride, 30
Electrochemical, 68, 162, 176, 339
  force, 175
  gradient(s), 82, 84, 91, 102, 107, 109, 140-142, 167, 168, 235, 339-341
  potential, 82, 84, 102, 107, 110
Electrode(s), 92, 137, 167, 339
Electrofusion, 78
Electrogenic, 110, 235
  pump(s), 154, 168, 339-341
Electromechanical, 168
Electromagnetic, 17-20, 26, 30, 31, 42, 45, 325, 327, 329
  field, 21, 31
Electron(s), 13, 17-24-31, 33, 35, 38-44, 47, 50, 51, 60, 62, 65, 66, 68, 78, 82, 84, 90, 106, 108-111, 143, 144, 186, 271, 272, 325, 332, 334, 339-341, 343
  microscopy, 75, 98, 111, 114, 118, 119, 124, 151, 155, 156, 183, 184
  polarization, 29, 47
  transfer reactions, 338, 339, 343
  transport, 82, 84, 110, 142, 186, 334
  tunnelling, 42
Electronic, 23, 30, 38, 43, 61, 68, 110, 330, 331
Electrophoresis, 14, 50, 106, 118, 172, 200, 339
Electrostatic, 14, 35, 58-61, 66, 67, 75, 336
Elongation, 152, 165, 180-186
Embryo(s), 72, 126, 180, 189, 204, 210-215, 217, 218, 223-225, 229, 230, 240, 249-259, 261, 263-268, 270, 352-355
  induction, 217
  patterns, 256-260
  polarity, 224, 257, 264
Embryogenesis, 13, 210, 213, 216, 218, 224, 238, 241, 252, 255, 259, 262, 266, 325, 352
Enantiomer(s), 44-47, 325, 326, 328, 334, 335
Enantiomorphs, 32
Endocrine, 93, 220
Endocytosis, 99, 101, 102, 180, 219, 342
Endonuclease, 51
Endoplasm, 129, 133, 134, 215, 261
Endoplasmic reticulum (ER), 59, 65, 74, 88, 95-100, 103, 148, 155, 164, 166, 180, 236, 342, 343, 354
Energy, 17, 19, 21-24, 27, 30, 31, 35, 37, 43-45, 51, 52, 58, 64, 67, 68, 74-76, 80-82, 84, 85, 87, 91, 92, 95, 100, 102, 104-111, 116, 119, 132, 140, 142, 167, 178, 198, 209, 235, 271, 328, 333, 334, 338-341, 343
  transduction, 74, 82, 89, 102, 109, 338
Entropy, 18, 19

Environment, 14, 30, 40, 43, 46, 47, 50, 51, 61, 66, 95, 101, 134, 142, 159, 181, 224, 233, 239, 352
Environmental, 138, 155, 163, 187, 197, 209, 226, 239, 252
  factors, 129, 172, 272, 356
  polarity, 79, 216
Enzyme(s), 46, 50-54, 56, 60, 64-66, 69, 73, 79-82, 85, 89, 93, 98-100, 103, 118, 123, 164, 166, 177, 186, 187, 194, 208, 220, 259, 337, 339, 340
Epidermis, 145, 175, 176, 185, 186, 210, 211, 228, 230, 261
Epigenetic(s), 201, 223, 224, 251, 358
Epithelium (epithelia), 104, 115, 146, 190, 218-221, 247, 260, 353
Equilibrium, 37, 102, 114, 119, 120, 159, 162, 222
Equipolar, 147, 181
Erythrocyte(s), 52, 62, 79, 137
Ethanol, 39, 43
Evolution, 46, 94, 192, 269, 271
Excitation, 42, 43, 51, 61, 74, 86, 88, 93, 108-111
Excited electrons, 23
  ionization, 271, 327, 329
Excretion, 130, 230, 235
Exocytosis, 90, 94, 98-102, 135, 219, 220

Fascin, 114
Fat, 104
Fatty acids, 39, 40, 62, 73, 96
Feedback, 92, 168, 173, 250
Female, 174, 196-200, 327
  basophilic gradient, 198, 199
  gametangia, 192, 198, 199
Fermentation, 215
Fern(s)
  gametophyte, 147
  leaf, 238
  mother cell, 210
  prothallia, 173, 174
  spores, 160, 173
Ferritin, 79, 135
Ferroelectricity, 26, 330, 331
Ferromagnetism, 26
Fertilization, 89, 157-159, 201, 204-207, 210, 212, 213, 215, 216, 224, 225, 252-254, 259, 261-263, 268, 269
Fibroblast(s), 62, 135, 137, 146, 342, 346
Fibronectin, 78, 134, 135
Field(s), 19, 22-27, 30-33, 142, 165, 175, 180, 189, 210, 212, 222, 223, 240, 245-247, 252, 272, 330, 331, 355
  polar, 205, 331
Filamin, 114
Filopodia, 122, 179, 180, 350
Fimbrin, 114
Flagella, 118, 121, 130-132, 138-140, 143, 195, 346
  polar, 201
Flip-flop(s), 56, 332
Flippase, 77
Flowering, 161, 197, 238, 239
Fluid(s), 37, 72, 77, 93, 101, 136
  mosaic model, 75, 77, 80
Fluorescence, 42, 61, 155, 175, 183, 188, 347
  polarity, 340
Fluorophores, 61, 108, 350
Flux(es), 25, 143, 207
Fodrin, 95, 221
Folic acid, 141
Foot, 135, 225, 247, 250, 340, 358
Formaldehyde, 46, 67
Formic acid, 39
Freeze, 102, 269
Fungal, 63, 105, 155-157, 162, 164-168, 181, 184, 187, 192-195, 228, 341, 343, 345
  conidia, 155, 181, 349
  cell(s), 161, 164, 204
  exosporulation, 192, 352
  germ tubes, 155-157, 184, 187, 188
  hypha(e), 107, 147, 165, 166, 169, 176, 186, 349
  mycelia, 164
  spore(s), 155, 160, 163, 325, 348, 352

G-protein(s), 81, 89, 113, 149
Galvanotropism, 180
Gametangia, 197-199
Gamete(s), 170, 195, 198, 215, 252
Gametophyte(s), 160, 161, 173, 224
Gamma (γ)-rays, 19, 21, 31, 47
Gap junction(s), 219, 249
Gas, 17, 18, 25, 28, 29, 327, 339
Gel, 78, 114

Gene(s), 15, 52-58, 70, 74, 148, 162, 163, 170, 189, 192, 196-198, 200, 204, 213, 223, 229, 243, 244, 246, 255-260, 268, 269, 272, 336, 356, 358
conversion, 56
expression, 15, 52, 53, 55, 56, 163, 181, 189, 238
polarity, 52, 199, 259, 272, 356, 358
targeting, 118
Genetic(s)
analysis, 55, 259
control, 208, 358
information, 57, 74, 132
Genome, 50, 51, 57, 189, 191, 211, 223, 260, 336
Germ tube(s), 108, 155-157, 160, 161, 163, 171, 181, 184, 187, 188, 204, 206, 325, 348
Germination(s), 155-157, 160, 163, 187, 196, 204, 205, 209, 348, 349, 354
Gliding, 132, 133, 139, 142, 143, 346
Globin, 52
Globular, 76, 115, 117
molecules, 60, 76, 77, 106, 111, 113, 119
Glucans, 166, 184
Glucose, 64, 167, 168, 183
Glutamic acid, 62
Glycine, 39, 40, 41
Glycocalyx, 78, 81, 129
Glycolipids, 99, 353
Glycolysis, 73, 92, 215
Glycoproteins, 78, 80, 81, 98-100, 177, 347
Glyoxysomes, 103
Golgi (apparatus), 73, 74, 79, 95-104, 121, 148, 166, 175, 178, 206, 207, 216, 342, 343
vesicles, 97, 99-101, 164, 168, 178
Gradient(s), 14, 23, 54, 56, 72, 73, 82, 87, 93, 104, 133, 139-142, 146, 160, 162, 163, 165, 170-172, 176, 180, 190, 195, 197-201, 205-207, 211, 215, 217, 222, 223, 230-233, 237, 239, 240, 247-250, 253, 255, 256, 261, 262, 264, 272, 338-341, 349, 354, 358
bioelectric, 354
differentiation, 197-200, 217
dissipation, 85
flowering, 239
inhibitor, 192
ionic (H^+, Ca^{2+},Cl^-), 162, 163, 341, 349
light, 209
metabolic, 208, 217, 255
morphogens, 15, 222, 223, 230, 240, 247, 354, 358
polarity, 205, 340
proton(s), 82, 83, 102, 108, 237, 338
protoplasmic, 205
redox, 264
RNA, 198, 199
spatial, 180
Grafting, 14, 208, 212, 225, 233, 242, 245-247, 249, 265
Gramicidin, 86, 133
Gravitation, 26, 216
field, 216, 234, 354
forces, 19
Gravitropism (Geotropism), 237, 341, 354, 355
curvature, 168, 352
response, 168, 186, 236
Gravity, 19, 33, 39, 172, 173, 209, 216, 234, 237, 238, 264, 265, 327, 341, 354, 355
perception-sensor, 354, 355
signal-stimulus, 236, 354
Growth, 13, 52, 68, 81, 113, 114, 117, 119, 122, 129, 131, 134, 146-150, 152, 154, 155, 158-160, 162-166, 169-174, 176, 177, 179-188, 191-194, 201, 206, 208-210, 212, 224-226, 228, 230-234, 236, 237, 241, 271, 344, 345, 348-351, 353, 357
axis, 147, 160, 173, 183
cone(s), 176, 177, 179, 180, 342, 349, 350
differential, 186, 236, 237, 271
direction, 147, 148, 186
elongation, 182-186, 188, 349
factor(s), 148, 149, 181, 226, 232, 354, 355
inhibitors, 236, 351
orientation, 148, 185
pattern, 160, 175, 348, 349, 357
polar, 133, 147, 181, 348-351
zone, 165, 169, 181
GTP, 119-121, 149, 253
Gyrase, 51

H, see Hydrogen
H_2O (see also Water), 15, 17, 35-38, 78, 82, 271, 332-334
Hadrons, 17, 19, 20
Haem, 60, 62
Hair(s), 175, 176, 208, 210, 211, 221, 246, 261
Hair pin model, 82
Handedness, 43-45, 48, 268, 269, 334, 356, 357
Haploid, 137, 195
Hapten(s), 67, 66
Head (cephalon), 15, 26, 59, 63, 115-117, 130, 211, 213, 218, 247-251, 257, 258, 260, 273, 345, 358
  gradient(s), 50, 51, 87, 113, 247-249
  group(s), 76, 78, 340
  regeneration, 249, 250
Heat, 29, 91, 190, 341
Helical (helicoidal), 50, 51, 55, 57, 59, 68, 70, 71, 86, 104, 115, 130, 131, 139, 267, 328, 334, 336, 345, 356, 357
  DNA, 50
  bacteria, 267, 356
  protein, 59
Helix, 44, 45, 47, 49, 50, 53, 58-60, 70, 71, 86, 87, 139, 327, 336
  alpha, 76, 86, 106, 117
  dipole(s), 58, 59
  double, 49, 50, 113, 336
Heme, 65, 66
Heterobipolar, 39, 41, 147, 181, 200-221, 326
Heterogeneity, 79, 171, 172, 195
Heterocysts (Cyanobacteria), 191, 192
Heterotrichous, 169
Histidine, 40, 65, 140, 337
Hole(s), 22-24, 51, 109, 330
Homeobox, 260, 350
Homeodomain, 260
Homeotic mutants, 256, 260
Homobipolar, 13, 39, 147, 148, 181, 185, 245, 326
Hormone(s), 93, 95, 101, 102, 172, 186, 209, 220, 227, 230-234, 236, 239, 354, 355
Hyaloplasm, 72, 104, 111
Hydration, 34, 73, 76, 330, 333
Hydrocarbon, 39, 40, 42, 43, 63, 76, 78, 109
Hydrogen
  atomic (H), 13, 17, 18, 20-22, 27-29, 35, 37-40, 49, 50, 55, 58-61, 66-68, 75, 76, 82, 85-87, 101, 102, 107, 109, 116, 120, 142, 176, 186, 194, 199, 236, 265, 270, 271, 328, 337
    bond(s), 34-37, 49, 55, 58, 63, 66, 76, 86, 96, 332, 333, 337
  ionic (H^+), 84, 109, 169, 175, 271
    channels, 87
    efflux, 235, 237
    gradient(s), 84, 102, 235
    pump (ATPase), 167, 220
  molecular (H_2), 17, 18, 82, 339
Hydrolytic (-ases), 65, 103
Hydronium (H_3O^+), 37, 38, 168, 333
Hydrophilic, 37, 39, 40, 63, 65, 75-77, 103, 106, 110, 249
Hydrophobic, 34, 37, 39, 40, 63, 65, 66, 75, 76, 78, 80, 84, 86, 96, 97, 106, 107, 141, 244
  domain, 77
Hydroxy(l) (OH^-), 37, 40, 68, 78, 82, 334
Hymenium, 226, 228
Hyperpolarization, 89, 90, 108, 141, 142, 154, 187, 221, 236, 340
Hypha(e), 63, 107, 129, 147, 157, 161-168, 174, 181, 192-194, 197, 199, 204, 205, 225, 226, 228, 271, 325, 349
  apex, 165, 190, 197, 200, 349
  pole, 204, 345
  tip(s), 105, 162-168, 174, 193, 194, 228, 349, 352

Imaging, 124
Immunochemistry, 66, 67, 103
Immunofluorescence, 112, 117, 124, 152, 346
Incompatibility, 195, 196
Indole-3-acetic acid (IAA), 159, 186, 230-232, 234, 235, 340, 355
  asymmetry, 237
Induction, 169, 200, 208, 215, 218, 222, 238, 239, 244, 246
  endosporulation, 190
  polarity, 266, 267
  prespore, 244
Information, 18, 23, 43, 56, 70, 89, 103, 140, 144, 145, 149, 155, 162, 181,

197, 198, 200, 211, 214, 224, 227, 236, 243, 259, 262, 343, 353
Inheritance, 218
Inhibition, 64, 93, 139, 148, 155, 195, 231, 248, 249, 344
  contact, 80
Inhibitor(s) 85, 99, 126, 187, 189, 192, 206, 211, 226, 228, 247, 351, 352
Insulin, 100, 101, 220
Integrin, 81
Interface, 34, 61, 75, 334, 338
Intermediate filaments, 111
Interposon, 55
Intestinal, 219
Ion(s), 17, 25, 34, 37, 38, 41, 43, 65, 66, 68, 75, 82, 84-91, 93, 94, 102, 104, 110, 135, 141, 142, 207, 249, 327, 329, 333, 337, 340, 343, 355
Ionic
  channel(s), 86-89, 91, 93-95, 154, 180, 340-342
  concentration, 201
  current flux(es), 110, 154, 181, 188, 230, 349
  gradient(s), 85, 175, 230, 236, 237
  permeability, 90
  transport, 104, 107, 341
Ionization, 17, 31, 42, 237, 329
Ionophore(s), 101, 133, 139, 160, 163, 170, 253, 261, 346
Iron ($Fe^{2+/3+}$), 14, 25-27, 60, 66, 74, 84
Irradiation, 169, 209
Isoelectric pH, 41, 164
Isometric, 38, 70, 133, 149, 205, 271
  growth, 155

Junctions, 112, 218, 267

K^+ (see also Potassium), 24, 40, 85, 87, 88, 91-94, 101, 106, 107, 141, 142, 154, 158, 175, 237, 333, 341
  channels, 87, 88, 90-92, 94, 216, 221, 341
  efflux, 194, 341
  ionophore, 107
Keratocytes, 145
Kidney (renal), 104, 105, 137, 218, 220, 221, 353
Kinase(s), 95, 148, 149, 162
Kinesin, 101, 123, 163, 179, 345
Kinetics, 43, 64
Kinetochore(s), 120, 124-128, 345
Kinetosomes, 244

Label(l)ing, 118, 131, 150, 153, 166, 204, 350
Lactic acid, 45
Lamellar, 63, 76
Lamellipodia, 179, 180, 346
Lamina-Laminin, 219, 220, 255, 256
Laser light, 23, 31
Lateral-posterior direction, 265
Lattice, 22, 24, 35, 38, 50, 64, 68, 72, 73, 79, 101, 111, 329
Layer(s), 75, 78, 129, 134, 150, 184, 201, 221, 225, 227, 232, 239, 330
Leading edge, 112, 135, 137, 144-146, 180, 346, 347
Leaf (leaves), 197, 205, 211, 230-232, 235, 238, 239
Lectins, 79, 80
Left-right polarities, 267-270, 328, 356
Leucine, 40, 47, 48, 60, 87
Leukocytes, 133, 137, 139, 141, 142, 146, 346, 347
Li^+ (Lithium), 158, 217, 255
Life, 20, 34, 45, 46, 48, 74, 127, 138, 225, 229, 267, 271, 273, 327, 334, 358
Life cycle(s), 170, 238
Ligand(s), 66, 76, 79, 80, 81, 85, 101, 113, 141, 235, 337
Light, 17, 23, 30-33, 43, 44, 46-48, 51, 66, 74, 80, 81, 87, 89, 94, 108-111, 129, 132, 142-144, 154, 159, 160, 169, 170, 172, 174, 189, 194, 201, 205-210, 214-215, 226, 227, 236, 242, 246, 258, 328-331, 340, 343, 352
  bioelectric response, 239
  energy, 84, 109
  excitation, 111
  perception, 89, 336
  polarization, 30, 32, 47, 124, 158, 174, 209, 210, 331
  transducers, 108
Limb, 223, 231, 265, 356
Lipid(s), 62, 63, 75-79, 97, 164, 177, 198, 331, 334, 338, 342, 344, 347

bilayer(s) (see also membranes), 72, 75-78, 87, 123, 338
flow model, 347
mosaic model, 76-78
transport, 97
Lipophilic, 235, 348
Lipoprotein(s), 63, 77, 82
Liver, 105, 249, 270
Locomotion, 126, 130, 132-136, 138, 144, 145, 179
Lomasome, 155
Lymphocyte(s), 99
Lysosome(s), 62, 95, 98, 99, 103, 164, 178, 220
Lysozyme, 59, 183

Macroconidium (-ia), 155, 349
Macrodipoles, 60, 61
Macromolecule(s), 14, 15, 34, 49-71, 73, 75, 79, 97, 155, 168, 170, 177, 206, 262, 271, 332, 336, 337, 358
conformation, 111
polarities, 49, 332, 358
signals, 89
Magnetic, 13, 24-28, 325, 330
dipole(s), 30, 330
field(s), 14, 21, 24-26, 28, 30, 48, 175, 327, 330, 331
moment(s), 27, 29, 331
monopole(s), 26, 27
particles, 108
polarization, 25-30, 330, 331
resonance, 30
Magnets, 13, 25, 27
Male, 161, 174, 197-200, 261, 327
gametangia, 192, 198, 199
gradient, 199
mitochondria, 198
mutant, 198
Maternal, 213, 218, 259, 267, 272
inheritance, 213, 214, 257, 259, 268, 269
mutations, 214, 256-259
Mating, 152-154, 195, 197, 269
type(s), 56, 195-197
Matrix, 42, 77, 78, 81, 84, 103, 105-107, 111, 130, 134, 181, 223, 255, 256, 347
Matter, 17-22, 24, 26, 27, 29, 44, 47, 67, 82, 147, 161, 271, 327-329, 334, 358

Mechanochemical
enzymes, 346
forces, 121, 123, 179, 180, 346
Mechanoelectric transducers, 221
Meiosis, 252
Membrane(s), 14, 63, 72-93, 95-102, 104, 106-111, 114, 115, 123, 130-133, 135, 137, 139-144, 148-150, 153, 154, 163, 177, 178, 180, 182, 186, 191, 201, 204, 218-220, 267, 333, 338-343, 346-348
apical, 98, 175, 220, 353
asymmetric, 168
cellular, 15, 34, 58, 75, 76, 81, 86, 88, 91-93, 95, 101, 104, 109, 115, 135, 149
differentiation, 99
domains, 204, 221
plasmic (see Plasma membrane)
polarity, 85, 110, 191, 338, 339
potential, 85-93, 106, 107, 146, 155-157, 167, 188, 236, 239, 338-342
primitive, 73
protein(s), 62, 76, 77, 79-81, 85, 96, 100, 103, 110, 175, 219, 221, 333, 343, 347
pump(s), 158, 167
receptor(s), 80, 89, 181
surface, 73-95, 101, 177, 332, 338-342
traffic-flow, 95, 102, 338, 347
Memory, 19, 23, 35, 95, 246, 329, 330
Meristem, 210, 223, 224, 230, 238, 239
cells, 147, 225, 230
Meromyosin, 112, 113, 121
Messenger RNA (mRNA), 53-55, 57, 58, 96, 155, 177, 208, 213, 214, 216, 217, 257, 259, 261, 264, 272
polarity, 58
transport, 124
Messenger(s),
chemical 89, 93, 94
Metabolism, 14, 53, 72, 73, 82, 85, 89, 91, 96, 100, 103, 132, 169, 170, 190, 217, 228, 233, 247, 255
gradient(s), 208, 217, 247, 255
transport, 82, 83
Metal(s), 22, 25, 68, 249, 339
ion(s), 40, 60, 65, 74, 337
Metaphase, 120, 126, 128

Methane, 38, 39
Methanol, 39
Methylation, 140, 348
Mg^{2+} (magnesium), 81, 135
Microbial spores, 14, 154
Microbodies, 103
Microconidium (-ia), 193
Microfibril(s), 162, 176, 211
Microfilament(s) (see also Actin-Myosin), 15, 81, 99, 111-113, 115, 117, 119, 121, 129, 130, 134, 138, 144, 157, 163, 164, 175, 177, 188, 199, 200, 211, 253, 267, 325, 344-346, 348, 350
  associated protein, 116
Microgravity, 236, 354
Micropolarity, 338
Microinjection, 142, 259
Microspikes, 179
Microtrabecular lattice, 73, 111
Microtubule(s) (see also Tubulins), 15, 81, 95, 101, 105, 111-113, 118-129, 132, 138, 139, 141, 144-146, 148, 151-154, 157, 163, 164, 166, 167, 173, 176-180, 186-189, 193, 199, 200, 206, 211, 222, 229, 251, 253, 271, 325, 342-344, 350, 357
  apical, 166
  assembly-polymerization, 119, 121, 126, 187, 189, 222, 345
  inhibitor, 152, 187
  MAPs (-associated proteins), 118, 350
  organizing centre (MTOC), 99, 121, 342, 343
  polarity, 121, 122, 126, 127
Microvillus, 115
Microwave(s), 17, 37, 327
Mirror-image, 18, 44, 45, 69, 246, 268, 270, 334
Mitochondria, 74, 82-84, 96, 97, 103-108, 110, 122, 130, 146, 154-157, 164, 176, 168, 170, 173-175, 178, 179, 184, 188, 190, 198, 205, 206, 209, 215, 218, 221, 261, 264, 336
  apical-subapical, 155, 167
  ATP (ATPase H^+ pump), 82-85
  bipolarity, 108
  Ca^{2+}, 106
  membrane(s), 83, 104, 107, 108
  segregation, 198, 199, 261
Mitogenic, 199
Mitotic
  figures, 104, 122-128, 139, 151, 172, 345
  spindle, 112, 120, 124, 125, 151, 201, 345
Model(s), 19, 25, 49-51, 56, 61, 67, 70, 75-78, 83, 86-88, 95, 97, 99, 101, 103, 108, 117, 122, 124-126, 128, 130, 132, 135, 137-139, 141-143, 152, 157, 162, 167, 179, 183, 190, 191, 199, 206, 210, 219, 224, 228, 235, 237, 241, 243, 245, 247, 250, 254, 256, 260, 269, 332, 333, 340, 341, 347, 352, 356, 358
  cell growth, 182, 183
  membrane systems, 108, 109, 338
  polarity, 22, 34, 88, 167, 183, 217, 220, 240, 246, 250, 356, 358
Modelling, 61, 67, 338
Molecular, 13, 14, 25, 29, 30, 34, 41, 42, 44, 46, 47, 50-52, 62, 63, 64, 66, 67, 69, 71, 72, 75, 77, 85, 89, 94, 100, 109, 110, 112, 117, 131, 140, 144, 145, 158, 170, 176, 177, 180, 189, 192, 215, 240, 243, 244, 256, 269, 271, 272, 332-335
  chirality, 43-48, 334-335
  dipoles, 15, 33-43, 332
  movement, 14, 33, 37
  orientation, 14
  polarity, 119, 121, 358
  self-assembly, 350
  structure, 13, 62, 85, 337
Monensin, 99, 101
Monoaxial patterns, 241-250
Monopodial, 133, 138
Monopolar, 130, 132, 147-181, 197, 202, 272, 325, 348-351
  apical growth, 163-181, 197, 348, 349
  assembly, 70
  axiation, 107, 348, 349
  budding, 153
  differentiation, 202
  dominance, 163, 188, 271
  germination, 155, 158, 171
  growth, 162, 167, 227, 348, 350
  molecules, 39
  outgrowth, 149-163
  pattern(s), 192-195, 352

regeneration, 251
Monopolarity, 133, 165, 187, 352
Monopole(s), 13, 27, 39, 61, 325
Morphogen(s), 14, 223, 228, 239, 240, 244, 249, 250, 253, 256, 259, 265, 272, 345, 356
gradient, 14, 256
transport, 248
Morphogenetic, 149, 151, 154, 162, 193, 200, 208, 209, 212, 213, 222-270, 273, 325, 354-358
determinants, 213, 253
factor, 265
field(s), 14, 228, 245, 251
gradient(s), 217, 250, 255, 256, 264, 358
movement(s), 241, 264
mutants, 154, 245, 257
polarizations, 222-270, 354-358
signal, 127
substances, 14, 354, 355
Morphopoiesis, 70, 337
Morula, 266
Mosaic model, 76, 77
Moss(es),
leaves, 211
protonema, 172, 173, 208-210
spores, 160, 208
Motion, 37, 43, 47, 51, 91, 110, 118, 125, 131, 132, 135, 137, 139, 143, 146, 179, 329, 332
Motor, 93, 94, 114, 118, 123, 131, 132, 140, 142, 143, 167, 179, 341, 343
Movement(s), 14, 38, 52, 62, 81, 87, 88, 90, 100-102, 112-116, 118, 120-123, 125-146, 151, 162, 175, 178, 180, 195, 214, 222, 231, 234, 262, 263, 332, 336, 346, 347
auxin(s), 230, 233, 237, 354
cytoplasm, 263
intracellular, 114, 130, 346
polarity, 126, 266, 346, 347
Mucopolysaccharides, 64, 78
Multipolar, 147, 187, 188, 226, 326, 332, 348
budding, 187, 247
germination (outgrowth), 147, 187, 188, 348
moment, 33, 332
Muscle(s), 85, 88-90, 93, 104-106, 112, 114-117, 179, 190, 247, 340, 344
Mutant(s), 53, 54, 56, 58, 59, 118, 132, 140, 142, 151, 152, 154, 183, 187, 188, 193, 204, 226, 245-247, 256-261, 268, 337, 344, 347, 355, 356
embryos, 257
morphological, 245, 256-261
Mutation(s), 53-55, 58, 70, 88, 154, 213, 252, 256, 257, 259, 260, 268, 269, 336, 356
Mycelium, 164-166, 193, 226, 340
Myelin, 351
Myofibril(s), 104
Myoplasm, 215, 216, 261
Myosin, 15, 80, 81, 111-118, 125, 129, 130, 134, 163, 167, 168, 179, 180, 211, 344-347, 358
gene, 118
kinase, 116, 118
fungal (myosin-like protein), 118
Myxamoeba, 124

N, see Nitrogen
Na^+, 37, 85, 89, 91-93, 106, 142, 158, 333
-ATPase (pump), 91, 92, 221
channels, 87, 91-94, 216
NAD, 82, 84
NADH, 186, 338, 340
NADP, 84
NADPH, 109
Negative, 18, 19, 22, 33, 35, 39, 41, 51, 53, 61, 68, 70, 85, 88, 90, 92, 94, 106, 108, 109, 131, 136, 140, 142, 143, 148, 167, 229, 325, 326, 330, 339, 345, 354
charge(s), 20, 33-35, 39, 40, 57, 64, 67, 82, 90, 108, 167, 175, 328, 345
electric potential, 235, 237, 327, 341
electrode, 209
Nerve(s), 68, 85, 86, 93, 149, 180, 181, 249, 252, 262, 342, 349, 350
conduction, 91
growth factor (NGF), 181
induction, 238
Neurite(s), 126, 176-181, 271, 325, 342, 349-351
Neuron(s), 87, 88, 90-95, 146, 176-181, 346, 350

cytoskeleton-neurofilaments, 177, 179, 180
Neurotransmitter(s), 93-95, 102, 177, 178
Neutron, 17, 22, 329, 333
NH_3 (NH_4^+), 38, 271, 353
Nigericin, 107, 108
Nitrogen (N_2), 40, 58, 60, 165, 192
fixing cell, 191
Nuclear, 20, 30, 43, 45, 47, 57, 135, 164, 169, 171, 198, 205, 208, 209, 244, 271, 327-329, 331, 345
cap(s), 199
differentiation, 193, 254
dipoles, 30
division, 125, 152, 205
fusion, 345
magnetic resonance (NMR), 30, 73, 78, 331, 333, 340
matter, 17, 18
membrane, 74, 95, 96, 128, 148, 151, 152
pore(s), 123, 124
Nucleation, 81, 114, 127, 128, 134, 344
Nucleus (nuclei), 17, 19-21, 28-30, 33, 35, 38, 72-74, 89, 97, 101, 104, 112-114, 123-128, 130, 137, 145, 146, 148-150, 152, 158, 161, 170-173, 188, 189, 193, 195, 198-200, 205, 206, 208-211, 214, 216, 218, 225, 236, 244, 252, 255, 258, 259, 271, 327-329, 331, 345
Nucleic acid(s) (see also DNA, RNA), 15, 49- 58, 69, 70, 74, 75, 214, 332, 336, 337
Nucleosomes, 53
Nucleosynthesis, 17
Nucleotide(s), 51, 57, 73, 119, 139, 157, 174, 256
Nutrient(s), 60, 93, 101, 169, 175, 203, 348

O, see Oxygen
Oligosaccharides, 75, 79
Ontogenesis (ontogeny), 160, 193, 224
Ooplasm, 215, 216, 254, 261
Operon, 53-55
Optical, 23, 30, 44, 45, 48, 61, 119, 155, 328
Oral (structures), 244-246
Organelle(s), 72, 89, 94, 96, 97, 100-102, 103-112, 118, 122, 123, 127, 130, 131, 138, 145, 146, 342-344, 349, 354
Organizer (organizing center), 124, 238, 241
Orientation, 13, 14, 29, 33, 41, 43, 62, 63, 79, 104, 112, 114, 116, 121, 122, 126, 132, 142, 143, 148, 151, 158, 159, 183, 185, 186, 190, 191, 205, 206, 208, 211, 212, 229, 238, 244, 261, 262, 331, 332, 336, 341
Oscillator, 89
Osmotic pressure, 182, 193, 237
Outgrowth(s), 108, 138, 149, 155, 157, 159, 160, 161, 169, 170, 180, 181, 184, 210, 232, 342, 348, 352
Oxalic acid, 39
Oxidation, 110, 340
phosphorylation, 85, 99, 106
reduction potential(s), 162, 166, 339
Oxygen (O-O_2), 24, 25, 35, 37, 40, 58, 60, 65, 66, 82, 91, 92, 162, 186, 192, 198, 327, 332, 339, 340, 343

Pancreas, 220
Parallel
dipoles, 38
polarity, 50
Paramagnetic, 26, 30
Paramyosin, 117
Parenchyma, 147, 233
Parity, 18, 44, 45, 47, 327-330, 334
Particle(s), 17-22, 26-31, 34, 43, 44, 48, 67, 69-71, 77, 111, 122, 131, 133, 201, 207, 271, 327-329
Patches, 80, 81
Pattern(s), 13, 14, 26, 61, 72, 115, 119, 131, 137, 138, 143, 145, 152, 154, 155, 159, 160, 165, 170, 172, 175, 182-185, 188, 189, 192-200, 207, 212, 215-217, 222, 223, 227, 228, 236, 238, 240, 241, 244, 246, 249, 250, 255, 256, 259, 260, 265, 268, 271, 272, 348, 349, 356, 357
formation, 154, 215, 222, 238, 247
polarizing current, 231
regulation, 217, 240, 241
Pennate, 147, 184
Peptide(s), 45, 53, 58-60, 62, 66, 80, 86, 87, 95, 107, 181, 249, 343

dipole(s), 59, 60
Peptidoglycan, 182
Perception, 236, 340, 343, 354, 355
Periodic, 88, 330, 336
Periplasm, 60, 194
Permeability, 82, 85, 87, 89, 91, 338
Peroxide(s)-Peroxidase(s), 65, 66, 164
Peroxisomes, 103
pH, 37, 40, 41, 50, 80, 82, 84, 101, 106, 129, 159, 163, 166, 185-187, 201, 206, 220, 223, 230, 235, 237, 340, 353
gradient, 84, 101, 102, 109, 159, 235
intracellular, 168
Phage(s), 53, 70, 71, 182, 337
Phalloidin, 116, 152, 153, 174
Phialide, 193
Phloem, 233
Phosphate(s), 40, 70, 55, 62, 63, 92, 100, 103, 149, 166
Phospholipase, 88
Phospholipid(s), 62, 63, 65, 75-78, 80, 96, 97, 107, 109, 338, 339
Phosphoprotein, 177, 346
Phosphorylation, 64, 84, 94, 103, 117, 118, 134, 140, 141, 181
Photo-
chemistry, 42, 47, 48, 108
excitation, 42
periodic induction, 239
polarization, 206
receptor(s), 89, 111, 142
dipoles, 174
synthesis, 43, 47, 48, 108-111, 142
apparatus, 74
magnetic particles, 108
reaction center, 110
system(s), 110, 343
taxis, 142, 143
transducers, 74
voltaic, 108
Photon(s), 17, 21-23, 27, 30-32, 47, 89, 108-111, 209, 329
Phycobilisomes, 111
Phyllotaxis, 197, 232
Phytochrome, 89, 174, 239, 340
Pigment(s), 81, 89, 100, 110, 142, 207, 213, 217, 242, 261, 269, 336, 340, 343
blue-green, 132, 133, 143
brown, 91, 159, 160, 169, 172, 195, 224, 244, 349
green, 119, 130, 143, 147, 169, 170, 185, 188, 190, 208, 228, 340, 341, 349
grey, 255, 262, 263
orange, 198, 199, 216, 254, 261, 262
red, 75, 111, 172, 185, 216, 220, 349, 353
yellow, 147, 169, 195, 216, 261,
Pinocytosis, 95
Plant(s), 13, 15, 32, 73, 79, 80, 89, 91, 101, 102, 124, 129, 147, 161, 169, 170, 172, 175, 185, 186, 189, 197, 200, 204, 208-210, 212, 222-225, 229-233, 235, 236, 238, 239, 268, 325, 340, 343, 354, 355
axis, 229, 233
cell elongation, 185
eggs-embryo, 154, 225, 325
growth substance(s), 186, 235, 355
Plasma membrane, 63, 74, 75, 77, 78, 80-82, 85, 89-91, 95, 97, 99-104, 106, 111, 112, 115, 132, 134-136, 141, 143, 149, 150, 154, 157, 162, 166, 173, 175, 185, 186, 195, 207, 216, 218, 219, 235, 269, 338, 352-355
domain(s), 218-220
polarization, 220
Plasma, 24, 137, 214, 327
Plasmalemma, 98, 142, 144, 164, 166, 167, 173-176, 180, 184, 194, 235-237, 254, 338
Plasmid, 118
Plasmodium, 129, 133, 143
Plate(s), 32, 60, 70, 131, 174, 221, 228
Polar, 13, 14, 33, 35, 37-41, 43, 53-55, 58, 60-62, 64, 66-68, 70, 73, 75, 76, 78, 80, 83, 86, 87, 97, 108, 111, 112, 115, 117, 119, 120, 125, 128-131, 135, 136, 137, 140, 143-145, 154, 160, 163, 166, 170, 172, 173, 181, 183, 189, 191, 198, 199, 201, 204, 211, 214, 215, 224-226, 228, 232-236, 241, 242, 244, 246, 247, 249, 267, 268, 271, 272, 331, 346-349, 352-354
blastomeres, 264
assembly, 179, 202
auxin transport, 233-235, 354

axiation, 13, 81, 147, 154, 160, 165, 173, 174, 200, 201, 206, 207, 212, 224, 228, 241, 242, 257, 258, 263, 265, 266, 271, 346, 353, 355
bodies, 212, 218, 266
bonds, 76
budding, 151
cell(s), 97, 176, 217-222, 266
development, 73
differentiation, 189, 193, 195, 201, 346
divisions, 157, 158, 205, 210, 211, 225
growth, 147, 151, 164, 173, 176, 186, 194, 348
movements, 15, 84, 112, 162, 232, 233, 266
conduction, 38
cytoplasm, 13, 200, 208, 214, 215
domain(s), 64, 107, 203
elongation, 161, 171, 173, 180, 181, 195, 201
genes, 259
gradient(s), 173, 176, 205, 234, 264, 345
granules, 256
group(s), 50, 55, 63, 75-78
liquid(s), 37, 68
lobe(s), 213, 252, 253, 255, 269
molecules, 14, 33, 35, 37-41, 43, 62, 63, 78, 80, 350
mutants, 54
pattern(s), 14, 26, 222, 239, 241
polymerization, 114
regeneration, 166, 234, 246, 251
segregation, 199, 343, 345
signal, 157, 261
site, 154

Polarimetry, 32, 331

Polarity, 13-15, 18, 23, 25, 34, 37, 40, 43, 50-57, 60-62, 66, 67, 72, 79, 81, 82, 86, 94, 98, 99, 101, 102, 107, 112-122, 124, 126-134, 137, 138, 143-145, 147, 148, 154, 157-160, 165, 166, 168-176, 179, 181, 183, 185-191, 200, 201, 204-210, 212, 214, 216-218, 220-222, 224, 225, 227-229, 231-234, 236, 238, 239, 241, 242, 244-252, 256-258, 260-263, 265-267, 271-273, 325-330, 332-334, 336-358
cellular, 157, 158, 229, 240
control(s), 22, 56, 62, 143, 157, 171, 222, 236, 238, 244, 245, 248, 256, 257
cytoplasmic, 210, 211, 262
developmental, 227, 257, 352
egg(s), 157-159, 210-212, 253-259
embryonic, 224, 225, 249, 257
hyphal, 166, 348, 349
intrinsic, 14, 15, 51, 115, 119-121, 132, 182, 244, 245, 248, 250, 271, 272, 358
inverse, 49, 58, 242
macromolecular, 14, 332, 334, 358
organismic, 225-239, 358
pigments, 216, 261, 340, 343
replication, 52
reversal, 14, 50, 51, 92, 133, 141, 143, 174, 207, 220, 232-234, 247, 265, 268, 272, 343
systems, 244
tissular, 14, 262

Polarizability, 332

Polarizable particles, 19, 23, 34, 330, 332

Polarization, 14, 17, 18, 24, 29-34, 37, 40, 41, 43, 45, 47, 48, 56, 89, 99, 101, 104, 105, 107, 109, 123, 127, 132, 137, 141, 145, 146, 149, 152, 155, 157-160, 177, 186, 205, 209, 210, 212, 216, 218, 220, 230, 254, 264, 266, 267, 327-333, 338-345, 348, 352-358
analyzers, 32
field, 18
light, 30-32, 331
magnetic, 25-30, 330, 331

Polarized, 13, 15, 23, 25, 28, 29, 31-34, 40, 47, 48, 50, 52, 60, 61, 64, 65, 79, 80, 97-99, 104, 106, 111, 113, 126, 131, 134, 138, 141, 142, 144, 145, 153, 155, 161, 162, 165, 166, 169, 173, 176, 198, 201, 211, 216, 218-221, 232, 240-243, 247, 256, 259, 265, 271, 273, 325-331, 336-341, 344, 345, 349, 350, 352, 353
actin, 168, 344
beams of particles, 30

bonds, 62, 85
communication, 243
conductivity, 22-25, 329, 330
control, 56
direction, 230
enzymatic reactions, 64, 65
flow, 180
form, 177
gas, 29
genetic expression, 198, 199, 358
growth, 15, 118, 129, 149, 155, 183, 226, 348-351
ionic regulation, 232
light, 32, 47, 124, 158, 174, 209, 210
movements, 126, 266
organelles arrangement, 180
organization, 14, 148, 172, 195, 236, 241, 246
orientation, 104
photons, 45, 329
secretion, 101, 220, 342, 343
spores, 155-157, 187
synapses, 93
translocation-transport, 62, 84, 101, 106, 107, 166, 178, 229, 233-236, 272
Polarizing field, 34
region(s), 265, 356
Polarography, 339
Polaron(s), 24, 51, 56, 68
Polarotropism, 174
Pole(s), 13, 14, 27, 33, 41, 49, 72, 82, 100, 107, 120, 124-126, 128, 130, 150, 158-161, 167, 171, 181-184, 190, 201, 204, 212-215, 217, 219, 220, 224, 229, 249, 254-256, 259, 263, 272, 325, 345, 352-355
north/south, 13, 28, 175, 246, 249, 325
rhizoidal, 158, 204-210, 352
thallic, 181, 204-210, 352
Poleward(s), 125-128, 345
Pollen
grain(s), 161, 163, 175, 205
tube(s), 147, 161, 164, 169, 174, 175, 186
Polyamine(s), 155, 348
Polyglutamic acid, 135
Polymer(s), 15, 64, 67, 68, 78, 112-114, 119, 121, 135, 183, 345
Polymerization, 15, 47, 70, 112-114, 119-121, 128, 131, 134, 179, 344-345
Polypeptides, 45, 55, 68, 196
Polypodial, 133
Polypolarity (also Multipolar), 133, 147, 326, 332
Polyribosome(s), 96, 103, 264
Polysaccharide(s), 64, 134, 153, 175, 187, 206, 237, 355
Pore(s), 75, 79, 86, 87, 99, 123, 124, 155, 160, 211
Porphyrin(s), 42, 60, 74
Positional, 117, 172, 176, 180, 197, 199, 223, 227, 241, 243, 244, 247, 256, 265, 358
control(s), 195, 222, 231, 243
DNA, 198, 199, 336, 358
information, 14, 173, 197, 209, 211, 223, 228, 240, 252, 260
Positive, 18-20, 22, 33, 35, 39, 40, 61, 65, 67, 68, 70, 83, 87, 90, 91, 93, 94, 102, 107-109, 140, 142-144, 148, 167, 168, 170, 325-327, 336-340
charge(s), 20, 33, 35, 59, 68, 71, 82, 91, 94, 168, 327-329, 338, 343
current, 161, 175, 194
electric potential, 235
electrode, 209
feedback, 230
gravitropism, 236, 237
hole(s), 22, 108, 109
ions, 236
Positron(s), 17-19, 21, 22, 31, 44, 271, 327, 334
Posterior, 256
pole, 213, 229, 245, 246, 256, 258, 263
region-segment, 244, 245, 250, 251, 257, 258, 261, 262-265, 346
structures, 252, 259, 346
Postsynaptic, 93-95, 180
Potassium (see also K^+), 24, 85, 91-94
Potential(s) (see also Electric-), 21, 30, 35, 42, 66, 74, 84-86, 88, 90, 91, 94, 109, 114, 131-133, 136, 142, 146, 148, 170, 176, 180, 225, 237, 243, 253, 272, 338-341, 346
depolarization, 236, 334, 346
difference(s), 89, 170, 230

gradient(s), 93, 94, 109, 170
polarization, 340
Prebiotic, 46-48, 57, 73
Precursor(s), 14, 57, 70, 74, 82, 103, 107, 124, 144, 166, 183, 191, 233, 252
Prepolar organization, 218
Pressure (see also Osmotic), 23, 35, 133, 182, 185, 193, 194, 237
Presynaptic, 93-95, 108
Primitive, 39, 73, 74, 108, 132, 137, 190, 265, 266
environment, 46
Probe(s) (see also Fluorescence), 50, 61, 152, 174, 204, 207, 340
Profilin, 114
Promotor, 52, 53, 55
Protease, 194, 259, 337
Protein(s), 13, 15, 34, 38, 45, 50-53, 55-63, 66, 68-83, 86, 87, 89, 94-104, 106, 107, 109-119, 122-124, 126, 129, 131, 132, 134-136, 139, 140, 148, 149, 151, 154, 155, 158, 161-163, 168, 169, 172, 174, 175, 177, 179-181, 198, 203, 204, 214, 218-221, 225, 235, 237, 243, 244, 256-261, 264, 269, 333, 336, 337, 339, 342-346, 350, 353
Proteoglycans, 78, 99, 219
Prothallia, 173, 174, 209
Proton(s), 13, 17-22, 27, 29, 30, 35, 37, 38, 41, 44, 60, 65, 82, 83, 87, 102, 106, 108-110, 132, 140, 142, 143, 167, 168, 175, 176, 186, 220, 230, 235, 271, 325, 333, 338, 339, 341, 343, 349
flow, 22, 176, 339
gradient(s), 82, 83, 102, 108, 235, 237, 335, 339
motor, 167
pump(s), 82, 102, 186, 220, 341
sink(s), 167, 168, 185
Protonema, 172, 173, 208-210
Protonmotive force, 84, 106
Protonophore(s), 108, 346
Protonation, 50, 154
Protoplasm, 13, 34, 72, 129, 133, 159, 165, 194, 205, 211
Protoplast(s), 78, 79, 162, 167, 202, 230, 237
Pseudoplasmodium, 241-243
Pseudopodium-pseudopodia, 126, 133, 134, 136, 138, 326, 342
Pump(s), 82, 93, 102, 106, 154, 158, 186, 220, 231, 341, 355
Purines, 49
Pyrimidines, 49
Pyrite, 108

Quadrupole(s), 38, 326, 331, 333, 340
Quantization, 19, 20, 29
Quantum, 17, 24, 26, 27, 29-31, 67, 42, 109, 329, 333
Quantum mechanics, 272, 328, 329, 333
Quantum theory, 29, 333
Quark(s), 19, 20, 329
Quartz crystal(s), 46
Quinone, 42

Racemic, 45-48
Radial, 112, 241, 148, 226, 262, 264, 271
Radiation(s), 17, 21, 25, 30, 33, 45, 47, 48, 67, 327, 331
Reaction
center(s), 110, 111, 343
-diffusion, 247, 249, 250
transfer, 339
Reactivity, 50, 337
Receptor(s), 60, 80-82, 93-96, 101-103, 107, 134, 135, 139-141, 143, 217, 220, 221, 235, 340, 341, 354, 355
Recognition
sequence, 336
system(s), 51, 57, 58, 79, 81, 96, 162
Red light, 89, 142, 174
Redox, 17, 61, 68, 74, 82, 143, 166, 186, 223, 264, 327, 339
Reduction, 54, 82, 84, 90, 91, 109, 110, 264
Regeneration, 13, 92, 132, 170-173, 177, 207, 225, 230, 240, 242, 245-248, 250, 251, 351, 352
Regulation, 51, 54, 86, 91, 114, 148, 157, 162, 184, 188, 189, 203, 350
Relativity, 17
Relaxation, 24, 42, 111, 133, 136, 340
Replication, 52, 53, 74
Reproduction, 172, 197-200, 238, 241
Resistance, 50, 67, 216
Respiration, 82, 103, 106, 166, 187, 188,

190, 198, 200, 215
Retina cells, 104, 181, 236
Retinal, 89, 341
Retinoic acid(s), 240, 244
Rhizoid(s), 147, 158-160, 164, 168-173, 181, 201, 204-210, 352, 353
elongation, 172
outgrowth, 205, 206, 352
Rhodamine, 152, 153, 155, 156, 174, 188
Rhodopsin, 81, 89, 141
Ribonucleic acid (RNA), 46, 52, 56-58, 70, 96, 124, 161, 166, 198, 199, 208, 214, 257, 336, 345
polymerase, 52, 57
viruses, 57
gradient, 198, 199
Ribosome(s), 58, 72, 83, 96, 97, 124, 172, 198, 199, 205
nuclear cap, 198
Root(s), 147, 163, 181, 185, 209, 210, 229-234, 236, 237, 268, 354, 355
apex, 225, 229, 231
cap, 176, 236, 355
hair(s), 147, 164, 169, 175, 176, 186, 205, 210, 211
meristem, 231
-shoot axis, 224, 225, 230
Rotation, 37, 44, 45, 52, 51, 64, 69, 139, 140, 245, 265, 268, 331, 333
Ruthenium red, 106

Sarcomere(s), 116-118, 344
Sarcoplasmic reticulum, 89, 340
Scaffolding, 70, 112
Scale(s), 18, 46, 82, 99, 100, 244, 327
Scattering, 23, 29-31, 124, 227, 343
Sclerotium, 226
Secretion, 86, 94, 98, 99, 101, 103, 104, 132, 137, 149, 150, 152, 177, 205, 207, 219, 220, 342, 343, 353
Segmentation, 169, 224, 259, 260
genes, 256, 259, 260
Segregation, 189, 200, 218
Self-assembly, 70, 189, 222, 357
Self-electrophoresis, 175
Semiconductor(s), 22, 68, 108, 329
Senescence, 238
Sensor(s), 141, 340, 341, 354, 355
Septation, 158, 181-183, 190, 191, 194, 195, 202, 205,
Sequence(s), 15, 50-58, 81, 86, 87, 94, 96, 97, 107, 121, 137, 157, 165, 184, 196, 204, 220, 226, 231, 256, 258, 336
Serine, 40, 87, 141, 259, 337
Severin, 114, 343
Sex (differentiation-disjunction), 153, 174, 197-200, 358
Shoot, 172, 185, 209, 229, 231-235, 237, 353
apex, 225, 229, 231, 232, 238, 239
axis, 224, 225, 230
meristem, 231
Signal(s), 14, 53, 70, 81, 82, 87, 93, 95-97, 100, 101, 106, 107, 118, 138, 140, 142, 143, 145, 148, 179, 182, 203, 209, 230, 231, 236, 237, 239, 240, 243, 252, 253, 256, 265, 266, 342, 353-355
inhibition, 185
intracellular, 102
morphogens, 240
peptide(s), 82, 88, 97, 106
receptor-recognition, 96, 97
transduction, 79, 350
target protein, 103, 353
Silicon (silica), 22, 108, 184, 330
Simulation, 222
Sink(s), 92, 157, 167, 168, 185, 222, 233, 240
Size(s), 20, 27, 34, 35, 40, 81, 93, 117, 137, 148, 149, 157, 161, 170, 173, 177, 182, 185, 189, 198, 200, 225, 228, 229, 240, 247, 250, 262, 331
Sliding, 76, 117, 120, 122, 125, 175, 345
Sodium (see also Na^+), 23, 49, 63, 68, 76, 90-93, 333, 341
Solar, 45, 48, 108, 109, 327, 330
Solitons, 51, 52, 68
Solvation, 333
Sorocarp(s), 241, 242
Sorting, 96-98, 100, 102, 103, 161, 177, 219, 220, 342, 343, 353
-out, 154, 198
Source(s), 22, 30, 45, 47, 48, 61, 92, 107, 132, 140-142, 173, 222, 233, 240, 206, 209, 328, 350

Spatial, 14, 15, 85, 95, 110, 121, 140-142, 163, 180, 190, 203, 209, 214, 221, 223, 259, 265
asymmetry-symmetry, 69, 271
organization, 112, 239, 259, 348
pattern, 207, 240, 252
polarity, 214, 257, 259
segregation, 183
Spatio-temporal, 73, 325
Spectra-spectrum, 30, 31, 61, 86, 89, 108, 331-333
Spectrin, 112, 114, 221
Sperm, 89, 254, 261-263
cells, 161, 218
Spherical, 34, 40, 63, 68, 69, 108, 131, 147, 149-154, 158, 159, 161-163, 187, 204, 229, 264, 325, 330, 348
bud(s), 149, 157
growth, 157
stage, 154, 325
Spin(s) 17, 22, 25, 27-30, 43, 44, 140, 331, 333
Spindle, 120, 124-128, 345
pole bodies, 151-153
Spiral, 45, 245, 268
Spitzenkörper, 105, 164, 166
Sporangia, 191, 194, 195, 352
Sporangiospore(s)-phores, 157, 163, 352, 354
Spore(s) 13, 155, 160, 169, 172, 173, 181, 187, 190, 191, 194-196, 202-205, 208-210, 224, 228, 241, 325, 348, 349
differentiation, 202
germination, 155, 173, 208, 348
induction, 195
unpolarized, 205
Sporulation
endo-, 190-192, 202
exo-, 192-195, 352
Spreading, 145, 199, 350
Stability, 13, 18, 22, 69, 127, 132, 183, 229
Stars, 25
Statocyte(s), 236, 354, 355
Statolith(s), 168, 236, 355
Stereospecificity, 15, 44-46, 86
Steroids, 63, 78
Stimulation, 90, 92, 141, 148, 227, 235
Stimulus (Stimuli), 22, 86, 95, 139-141, 143, 145, 206, 210, 220, 221, 223, 239, 243, 253, 329, 341, 355
transducers, 236
Stomata, 205, 211
Stress, 115, 126, 147, 149, 182. 186
Structural proteins, 58, 73
Subapical, 155, 165, 168, 169, 173, 175, 235, 349
zone(s), 163, 164
Substitution, 54
Sucrose, 206, 207, 222
Sugar(s), 44-46, 60, 64, 73, 79, 165, 233, 334
Sulfur (SH_2, SO_2), 38, 84
Superconductivity, 23-25
Superoxide dismutase (SOD), 61, 66
Surface
charges, 237
membrane(s), 73, 81, 90, 91, 101, 177, 333, 337-339
potential(s), 230, 340
proteins, 77, 332, 337, 347
structures, 203
Symmetry, 13, 18, 19, 44, 45, 47, 51, 64, 68-70, 72, 79, 123, 147, 154, 158, 159, 182, 221, 226, 246, 262, 265, 327-330, 334, 336
bilateral, 328
mutant, 268
pattern, 255, 269, 330
radial, 226, 262
spatial, 69
Symport, 82, 167, 168
Synapse(s), 87, 93-95, 105, 122, 178, 180, 181
polarity, 177, 178
transmission, 94, 95, 180
vesicle(s), 90, 94, 177, 178
Synapsin, 94
Synthetic, 23, 52, 74, 77, 93, 109, 110, 166, 185, 198, 235
enzymes, 183
polymers, 67

Target(s), 30, 53, 81, 89, 96, 97, 99, 106, 122, 157, 162, 177, 178, 180, 181, 219, 230, 349, 350

Targeting, 81, 97, 101-103, 107, 219
signal(s), 97, 103, 106, 353
Tartrate, 44
Taxis (Chemo-, Photo-), 139-144
Taxol, 121
Temperature, 17, 24, 25, 63, 68, 76, 80, 129, 154, 159, 161, 165, 175, 182, 187, 193, 226, 267, 268, 356
Template(s), 35, 52, 53, 55, 57, 58, 69, 122, 132, 243
Temporal, 15, 95, 133, 140, 141, 143, 163, 180, 190, 203, 251
Tetrahedral, 39, 64, 65, 332
Tetrapolarity, 196, 340
Thalli, 181, 204-210, 352
Theory, 14, 17, 20, 24-27, 31, 92, 131, 134, 223, 255, 327, 355
metabolic gradients, 247, 255
Thermodynamic(s), 14, 75, 128, 272, 337, 341
Thiol, 40, 162
Thylakoid(s), 74, 79, 108-110, 143, 343
Time, 17, 18, 30, 37, 51, 70, 72, 87, 92, 94, 96, 98, 102, 112, 124, 125, 139-141, 157, 159, 164, 175, 179, 181, 182, 190, 195, 200, 206, 207, 209, 210, 214, 215, 218, 226, 231, 234, 240, 244, 253, 257, 269, 270, 273, 330, 341
Tip(s), 114, 115, 131, 144, 164, 167-169, 173, 175, 176, 193, 195, 233, 349
acidic, 167, 168
growth, 150, 162, 163, 165, 167, 168, 169, 352
organelles, 167, 173, 178
Tissue(s), 62, 130, 137, 147, 169, 177, 186, 189, 201, 208, 224-228, 230-233, 237-240, 247-250
polarity, 230-234, 261, 262
regeneration, 241, 242, 248
Titanate, 23, 330
Topology, 26, 50, 83, 102, 162, 174, 191, 358
Torque(s), 36, 37, 140
Trace, 108
Traffic (intracellular), 97-100, 122, 148, 177, 256, 343
Tranducers, 109
Trans, 52, 97-101, 103, 260
Transcellular, 104, 137, 154, 168
calcium, 106
electrical potential, 170
ion current(s), 154, 161, 167, 349, 353
Transduction, 140, 142, 143, 236, 338, 348, 355, 358
Transformation, 80, 133, 137, 138, 139, 157, 162
Translation(s), 44, 51, 53-55, 58, 60, 69, 70, 96, 97, 132, 196, 214
Translocation, 51, 52, 54, 82, 83, 85, 96, 97, 106, 107, 123, 132, 169, 203, 204, 236, 239, 333
Transmembrane, 77, 81, 84, 86, 87, 90, 94, 102, 110, 132, 136, 140, 340, 341, 346, 353
domains, 261
potential(s), 89, 107, 339
receptor protein(s), 42, 77, 86, 90, 112
Transmission, 32, 86, 93-95, 105, 107, 343
Transport(s), 24, 60, 62, 78, 79, 82, 83, 85, 86, 89, 94, 97-106, 112, 122, 140, 143, 152, 163, 177-179, 191, 207, 219, 220, 231, 233, 235, 338, 341, 342, 343, 355
Transposons, 55, 336
Treadmilling, 113, 114, 118, 120, 125
Tree, 147
Triaxial patterns, 267-270, 356
Trichoblasts, 205, 211
Trichome, 107, 133, 143, 211
Trigger(s), 90, 93, 203, 215, 233, 239, 243
Triplet(s), 54, 57
Tripolar, 326, 329
Trophoblast, 266
Tropisms (tropic curvatures), 181, 235-238, 354-355
Tropomyosin, 114
Tubular, 70, 99, 104, 163, 252, 340, 341
Tubulin(s), 15, 81, 112, 114, 118-121, 125, 128, 129, 139, 151, 153, 163, 174, 177, 180, 187, 194, 200, 218, 325, 344, 349, 358
α- and β-, 111, 119, 121, 152
gene(s), 151, 187
membrane, 187
mutations, 193
Tumoral cells, 115, 149, 160
Tunnelling, 35, 38, 42, 67, 272, 336

Turgor pressure, 147, 162, 166, 186, 187, 230

Uncoupling agents, 108
Unidirectional, 15, 90, 97, 107, 111, 115, 119, 120, 132, 136, 182, 345
Unification, 20, 26, 27, 45
Unipolar, 147, 183, 240
Unity, 20
Universe, 17-19, 26, 27, 45, 271, 327, 328
Unpolarized, 28, 62, 205, 212, 329
Uptake, 94, 102, 106, 110, 340
Urea, 115
UV-irradiation, 214, 215, 257, 258

Vacuole(s), 129, 130, 137, 155, 164, 173, 184, 185, 194, 195, 225, 244
Valence, 22, 23, 24, 68, 328
Valinomycin, 107, 108
Vascular systems, 224, 225, 229, 231-233, 237
Vector(s), 26-29, 33, 44, 249, 336, 350, 352
Vectorial, 79, 82, 85, 89, 124, 142, 151, 166, 219, 220
  movement, 102, 200, 353
  mitochondrion, 106
Vegetal, 212, 214-216, 253, 255
  cortex, 214, 261
  pole, 190, 212, 253-255, 261, 263, 264, 269
  region, 217, 252, 255, 262
Vegetative, 147, 164, 165, 169, 190, 194-197, 203, 208, 226, 229, 231, 238, 239, 241, 352
  buds, 239
  cell(s), 161, 191, 192, 202, 205, 228
  differentiation, 193
  growth, 238, 241
  pole, 161
Ventral, 231, 256, 263
Vesicle(s), 74, 85, 94, 95, 97-102, 105, 110, 122-124, 137, 151, 153, 155, 157, 161-164, 166-168, 173, 175, 177-180, 183, 184, 194, 195, 204, 206, 207, 215, 235, 340, 342-345
  membrane, 102, 109, 342
  secretion (granules), 101, 207
  transport, 151
Vibrating probe (electrode), 154, 168, 194, 207, 230
Villin, 114
Vimentin, 111
Vinculin, 144
Virus(es), 57, 69-71, 117, 219
  DNA, 58, 337
  form (TMV), 69, 70
  RNA, 57
Vision, 89
Vitamin B_1, 160
Vitellogenesis, 100
Voltage gradient, 167

Wall(s), 15, 100, 129, 133, 134, 148, 150-153, 155, 157-159, 161, 162, 165-168, 175, 176, 182, 183, 185, 186, 193-195, 199, 206, 207, 209-212, 224, 225, 230, 236, 237, 256, 267, 341
  apical, 164, 166
  cell, 64, 79, 149-155, 157, 162, 166, 169, 175, 176, 183-187, 189, 201, 203, 206, 207, 211, 222, 223, 226, 230, 235, 352, 356
  vesicles, 167
Water (see also H_2O), 17, 34-41, 51, 55, 58-68, 73, 75-77, 104, 110, 155, 159, 169, 175, 228, 233, 246, 268, 325, 327, 332-334, 338, 343, 352
  cell, 331
  dipolar, 34-38, 332, 333, 338
  -splitting, 343
  surface-interfaces, 63, 76, 333, 338
Wing, 240, 260, 261, 265
Wound, 176, 250, 251, 341

X-ray(s), 35, 37, 78, 86, 110
Xylem, 233

Yeast(s)
  budding(s), 150, 154, 184, 187, 344, 348
  cell cycle, 151-154
  cell polarity, 152, 161
  cytoskeletal network, 342, 344, 348
  elongation (fission-), 183, 184
  forms, 161-163
  mating, 152-154, 195-197
Yellow egg crescent, 216, 261

Yin-Yang, 13, 138, 148, 271
Yolk, 190, 212, 216-218, 269, 270

Zinc (Zn^{2+}), 58, 59, 61, 337
Zone(s) (cellular zonation), 104, 117, 129, 133, 134, 161, 165, 168, 171, 173-178, 185, 195, 199, 214, 230, 236, 237, 245, 248, 256, 262, 350, 352, 356
  elongation, 230
  exclusion (mitochondria), 103-105, 166-168, 193
Zoospore(s), 134, 169, 195, 204
Zwitterion, 41
Zygospore, 169
Zygote(s), 151, 158-160, 169-171, 184, 195, 196, 201, 204-207, 210, 213, 214, 224, 225, 252
  differentiation, 14
  germination, 205

TAXONOMIC INDEX

Acanthamoeba, 116, 344, 346
Acetabularia, 170, 171
  A. mediterranea, 208
  A. Wettsteinii, 208
Achlya, 194
  A. bisexualis, 165,
  A. debaryana, 194
Actinomycetes, 164
Agaricus, 226, 227
  A. bisporus, 225, 226
Agrobacterium tumefaciens, 164
Algae, 73, 130, 132, 147, 168, 181, 188, 228, 229, 340, 341, 344, 346, 352, 353
Allium, 211
Allomyces, 147, 166, 181, 192, 194, 195, 197, 199, 200, 204, 205, 349, 358
  A. arbuscula, 194, 197-199
  A. javanicus (hybrid), 199
  A. macrogynus, 197, 199
Amblystoma mexicanum, 262
Amoebae, 133, 134, 136, 138-141, 243, 326
Amoeba proteus, 134, 136, 143
Amphibians, 204, 212, 216, 217, 223, 238, 262-264, 270, 272, 355
Anabaena, 192
Anise, 349
Anthoceros, 225
Aquaspirilla, 267
Arabidopsis thaliana, 355
Arthrobacter, 164
Arthropods, 355
Ascaris, 252
Ascidians, 215, 216, 254, 261, 262, 272
Ascobolus, 56
  A. immersus, 56
Ascomycetes, 155, 196
Aspergilli, 193
  A. nidulans, 193, 345
  A. aureolatus, 193
Azolla, 268

Bacillus, 167, 202
  B. brevis, 86
  B. subtilis, 182, 191, 267, 356
Bacteria, 41, 53, 55, 60, 103, 110, 130-132, 139, 140, 149, 150, 164, 182, 190, 201, 267, 356
  budding, 149, 150
  helical, 267, 356
  photosynthetic, 110
Bacteriophages (fd, l), 53, 69-71, 337
Basidiomycetes, 225, 226, 228
Bipolaris, 184
Birds (chick), 81, 121, 146, 181, 217, 265, 266
Blastocaulis, 150
Blastocladiella emersonii, 194
Blepharisma, 268
Boltenia, 216, 254
  B. villosa, 261
Botrydium, 169
Botrytis cinerea, 187, 334

Caenorhabditis elegans, 213, 251, 252
Callitriche, 211
Candida albicans, 162, 163, 348
Capsella bursa-pastoris, 225
Caulerpa, 344
Caulobacteria, 201-203
Caulobacter crescentus, 202, 203
Cecidomyids, 214
Chaetophorales, 169
Chaos chaos, 137
Characeae, 168, 338
Chara, 130, 163, 168, 169, 205
Chick, 266
Chironomids, 215
Chlamydomonas, 119, 121, 132, 143, 228, 346
Chlorococcales, 229
Chlorophyceae (Green algae), 119, 130,

143, 147, 169, 170, 185, 188, 190, 208, 228, 340, 341, 342, 344, 346
Ciliates, 244
Cladophorales, 147
Cladophora glomerata, 207
Clavelina, 262
Coleoptera, 214
Chrysomelid, 214
Coelenterates, 246, 250
Conjugatophyceae, 340
Coprinus, 225, 226
C. cinereus, 226, 352
C. congregatus, 226
C. stercorarius, 225
Corn (see also *Zea*), 354
Corynebacterium, 164
Cryptogams (see also ferns and mosses), 181, 208
Cyanobacteria (Blue-green algae), 111, 132, 133, 142, 143, 190-192

Dentalium, 253, 269
Desmid(s), 147, 188
Diatom(s), 132, 147, 185
Cymbella, 184
Navicula, 184
Dictyostelium, 116, 118, 134, 242, 243, 346, 347
D. discoideum, 124, 133, 140, 141, 143, 241-244, 347
Dictyota, 205
Diptera, 214, 257
Drosophila, 13, 62, 124, 213, 214, 216, 217, 256-261, 344, 356
D. melanogaster, 259, 261
Dryopteris, 160, 169, 174
D. filix-mas, 174

Echinoderms (sea-urchin), 89, 120, 126, 212, 253, 254, 264, 272
Enteromorpha, 208
Eremosphaera viridis, 341
Equisetum, 160, 205, 209, 210, 224
Escherichia, 88
E. coli, 52, 55, 64, 82, 140, 182
Euglena gracilis, 143
Eukaryotes, 107, 151

Ferns, 147, 160, 173, 174, 189, 190, 210, 232, 238, 268
Fishes, 147, 217, 265
shark, 265
Flagellate(s), 99
Flammulina (Collybia) velutipes, 226
Flexibacter, 132
Fomes, 225
Foraminifera, 268
Formica, 214
Frog, 263
Fucales, 201, 352
Fucoid algae, 182
Fucus, 81, 157-159, 204, 206, 208, 210, 224
F. furcatus, 158
Funaria, 160, 163, 164, 173, 209
F. hygrometrica, 160, 172
Fungi, 56, 101, 129, 134, 147, 155, 163-165, 168, 184, 194-196, 225, 340, 341, 352
higher (mushrooms), 227, 354
imperfecti, 155

Globigerina, 268
Griffithsia, 172, 353
G. pacifica, 185

Halicystis, 91
Halobacterium halobium, 110, 142
Hansenula, 64
Human, 133, 266, 273, 334
Hydra, 246-250, 358
H. attenuata, 248
Hydractinia, 250
Hydroids, 170
Hydrozoa, 241, 246, 249, 272

Ilyanassa, 253
Insects, 217, 256-260, 270, 356
Iris, 326

Kloeckera, 187

Laminaria, 224
Leafhoppers (Cicadellids), 215
Lentil, 349
Lepidoptera, 214
Lilium grandiflorum, 161
Lilium longiflorum, 175
Liverworts, 173, 174, 209

Lymnaea, 269
L. peregra, 268, 269, 356
L. suturalis, 269

Mammals, 212, 266, 356
Marchantia polymorpha, 173, 209
Micrasterias, 147, 188
Molluscs, 212, 213, 252, 268, 269, 272, 356
Monilia, 185, 193
M. fructigena, 105
Monstera, 210
Mosses, 147, 160, 172, 173, 188, 197, 208-211
Mouse, 266, 356
Mucorales, 162, 196
Mucor racemosus, 157, 162
M. rouxii, 162, 163, 348
Mycetozoa, 241
Mycobacteria, 164
Mycobacterium, 164
Mycoplasma, 132, 133
Myxobacteria, 132

Nadsonioideae, 184
Nadsonia, 187
Naegleria, 138, 139
N. gruberi, 138
Nassarius, 253
Neurospora, 118, 165, 196
N. crassa, 56, 102, 108, 129, 155, 156, 165, 167, 187, 193, 195, 349
N. sitophila, 195
Nicotiana tabacum, 239
Nitella, 116, 130, 185
N. axiliaris, 185
Nitrobacter, 150
Nocardia corallina, 164
Nostocaceae, 142

Oedogonium, 169
Oncopeltus, 176
Onoclea sensibilis, 173
Oomycete(s), 166, 349
Oscillatoriaceae, 142
Osmonda, 160

Paracentrotus lividus, 213
Paramecia, 244
Paramecium, 130, 141, 142, 244
Pasteuria, 149
Pea, 234
Pelvetia, 207, 210
P. fastigiata, 207
Penicillia, 193
P. claviforme, 193
Phaeophyceae (Brown algae), 91, 159, 160, 169, 172, 195, 224, 352
Phormidium, 133, 142, 143
P. uncinatum, 132
Phycomycetes, 204
Phycomyces, 352, 354
P. blakesleeanus, 129
Phyllanthes, 238
Physarum, 129, 138
P. polycephalum, 133, 137, 143
Physcomitrella, 209
Pinus sylvestris, 197
Planaria maculata, 251
Planctomyces, 149, 150
Pleurococcoid, 147
Pleurochrysis, 99
Podospora anserina, 196
Polyporaceae, 225
Polyporus brumalis, 226, 227
Prokaryotes, 53, 54, 96, 129, 132, 133, 139, 140, 142, 143, 149, 164, 182, 336
Protists, 107
Protosiphon, 169
Protozoa, 104, 132, 141, 244, 245, 268, 272

Rat, 351
Reptiles, 217
Rhodnius, 176
Rhodophyceae (Red algae), 111, 172, 185, 345, 353
Rhodopseudomonaceae, 110
Rodents, 267

Sabella, 251
Saccharomyces cerevisiae, 150-153, 336, 345, 348
S. uvarum, 152
Saccharomycodes ludwigii, 184
Salmonella, 131
Saprolegnia, 194
S. ferax, 349
Scenedesmaceae, 229
Schizophyllum commune, 196, 226

Schizosaccharomyces pombe, 183
Selaginella, 231
Seliberia, 150
Serratia marcescens, 242
Sinapis alba, 239
Slime mold(s), 116, 118, 129, 133, 134, 137-140, 241, 242, 346, 347, 348
Smittia, 257
Snails, 356
Sphacelaria, 172
Sphagnum, 197, 205, 211
Spirillum, 131
Spirochaeta, 131
Spirogyra, 147, 169
Squid, 90, 91, 94, 122, 179
Stentor, 245, 246, 268
Streptomyces, 164
  S. streptomycini, 164
Styela, 216, 261

Tetrahymena, 57, 244-246, 268
Torpedo californica, 341
Trichoderma viride, 155, 156, 340
Tubularia, 247
Tunicates, 215, 261

Uromyces appendiculatus, 349

Vaucheria, 147, 169, 195
Viruses, 57, 69, 219
  Tobacco Mosaic Virus (TMV), 69
Volvocaceae, 228
  Eudorina, 229
  Gonium, 229
  Pandorina, 229
  Volvox, 229

Worms,
  Annelids, 213, 249, 355
  Nematodes, 213, 251, 252
  Planarians, 250, 251
  Polychaetes, 251
  Sabellids, 268

Xanthophyceae (Yellow algae), 147, 169, 195
Xenopus, 217
  X. laevis, 262

Yeast(s), 56, 64, 97, 101, 107, 149-153, 161, 162, 181, 184, 187, 196, 326, 345, 347, 348
  fission, 183

Zea (see also corn), 231
  Z. mays, 354
Zygnematales, 147
Zygomycetes, 196