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Research in Advanced Concepts in Biotechnology, Human Analogs and Bionics

Final Report
30 October 1964

Contract No. NASw-780

Submitted to:

Director, Biotechnology and Human Research
Office of Advanced Research and Technology
National Aeronautics and Space Administration
Washington 25, D.C.

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TELEDYNE SYSTEMS CORPORATION
12525 South Daphne Avenue
Hawthorne, California

ABSTRACT

13831

This is the final report submitted under NASA Contract NASw-780, "Research in Advanced Concepts in Biotechnology, Human Analogs, and Bionics." The title of this research effort is a fine descriptor of the effort that has been expended. Teledyne Systems Corporation has conducted research into the biotechnology of three of the subsystems of man: an energy input subsystem, a distribution and control subsystem, and an energy output subsystem. Human analogs are developed by the utilization of the Man-Machine Methodology, which was formulated for the Director of Biotechnology and Human Research under NASA Contract NASw-567. Finally, bionic applications using human anlogs are made for each of the subsystems studied, and a bionic system, which includes an application from each of these subsystems, is suggested. Author

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1.0 INTRODUCTION

This is the final report submitted under NASA Contract NASw-780, "Research in Advanced Concepts in Biotechnology, Human Analogs, and Bionics." The title of this research effort is a fine descriptor of the effort that has been expended. Teledyne Systems Corporation has conducted research into the biotechnology of three of the subsystems of man: an energy input subsystem, a distribution and control subsystem, and an energy output subsystem. Human analogs are developed by the utilization of the Man-Machine Methodology, which was formulated for the Director of Biotechnology and Human Research under NASA Contract NASw-567. Finally, bionic applications using human analogs are made for each of the subsystems studied, and a bionic system, which includes an application from each of these subsystems, was suggested.

In this introductory portion of the report, it would be beneficial to discuss the concepts that have been used in the establishment of the human analogs developed by Teledyne. The format of the human analog has been taken from the Man-Machine Methodology. Basically, the methodology is a hierarchy of matrices of different levels of complexity that relate man and machine to the four influencing factors of environment, function, configuration, and material. There are four information sheets to record specific data related to environment, function, configuration, and material. Together the matrices and the information sheets establish the format of the human analog.

Thus, the human analog appears as groups of information sheets, the exact relation of each of these groups being established by the Man-Machine Matrices. The relationships of each of the groups of information sheets (these groups will later in this report be called files) is fixed by the Matrices. The Matrices were very carefully developed to insure that the correct relationships were established between the four influencing factors and the man utilized in the system, the machine utilized in the system, and the container of the system. Therefore, an individual obtaining data, e.g., a physiologist gathering biological data need not concern himself with interrelating data. He needs only to conscientiously fill out the information sheets for all those matrix intersections that he feels are involved in his research effort. As this report clearly illustrates, each of the separate files that have been generated discusses only one aspect, only one interaction between an influencing factor and a subsystem of man, and yet all of the various files are clearly related by the Man-Machine Matrices. In the gathering of data, the researchers were greatly assisted because of the strong organizational influence of the Methodology.

Cognizant NASA representatives have chosen to direct Teledyne to analyze one of man's energy input subsystems, one of man's distribution and control subsystems, and one of man's energy output subsystems by means of the Man-Machine Methodology. Teledyne has selected the eye, the nervous subsystem, and the musculo-skeletal subsystem as the respective input, distribution and control, and output subsystems to be analyzed.

Section Two of this report contains an analysis of the operation of the human eye. This analysis represents the first rigorous application of the Methodology to a research problem. Work began by deciding the methodological level (hierarchial matrix level) that was appropriate to develop the human analog of the eye. Then the environment of the eye was described by utilizing the information sheets of environment, function, configuration, and material. Next, the various functional aspects of the visual subsystem were examined. Functional, configurational, and material information sheets were completed for each of the functional aspects. Following the functional examination of the subsystem, the configurational aspects were developed. Drawings were made to illustrate those configurational aspects that were of interest in the examination of the eye. Finally, the material information sheet was filled out to provide a listing of all of the parts of the subsystem.

Section Three of this report presents an examination of one of man's distribution and control subsystems. The nervous subsystem of man is discussed and a non-numeric data handling element is developed that is based on the operation of the neuron. Following this section, there is an examination of one of man's output subsystems. The musculo-skeletal subsystem has been selected and is examined basically from the viewpoint of the kinesiologist. The various body joints, their respective angles of movement, the specific motions produced by the muscles, bone strength, and the types of muscles are discussed with the intent of interesting multidisciplinary investigators in the bionic possibilities of the human musculo-skeletal subsystem.

An example of one of the bionic possibilities that is cited is the utilization of the principles of human joint connections in hostile environments where the joint lubricant may escape or unwanted particles may penetrate a seal, such as the commonly-used rotary seal.

Another area to which kinesiologic information can be transferred is that area concerned with manipulators. Autonetics Division of North American Aviation, Inc., is currently developing a rather sophisticated manipulator for undersea oil drilling. The Public Relations Department of Autonetics has kindly allowed the use of the illustration on the following page (Figure 1), which shows the manipulator of the Beaver engaged in an actual undersea task. The last portion of Section 4 of this report presents an article from the 4 April 1965 edition of the "Los Angeles Times" about undersea manipulators such as the Beaver.

Section Five is an effort at tying the bionic suggestions made in each of the preceding parts of this report into one system. To this end a goal seeking visual sensor is developed. The next section presents the concluding remarks for "Research in Advanced Concepts in Biotechnology, Human Analogs, and Bionics." Following the Conclusions, there is a Bibliography.

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Figure 1. Manipulator developed by Anaheim Autonetics Division of North American Aviation, Inc., is used on The Beaver, which is a two-man submersible.

2.0 INPUT SUBSYSTEM

2.1 INTRODUCTION

Research in Advanced Concepts in Biotechnology, Human Analogs and Bionics begin with a review of the literature concerned with the physiology and anatomy of man. The human body was studied with emphasis on those subsystems that handle information. Study was directed toward examining how man inputs, distributes and controls, and outputs information. These three categories were used to classify the subsystems of man. This breakdown is shown in Table 1.

From Table 1, one subsystem from each category was selected to be analyzed. The visual, nervous and musculo-skeletal subsystems were chosen. The major criteria used in selection was that each represented the subsystem of greatest apparent channel capacity when examining input, distribution and control, and output respectively. These three categories are basic to the Man-Machine Methodology that was developed for the Director of Biotechnology and Human Research under Contract NASw-567. The Man-Machine Methodology is explained in the final report submitted under that contract. The reader who is not familiar with the Methodology is referred to that final report.

Using the Man-Machine Matrices and the Information Sheets, which are both portions of the Methodology, a format for the establishment of the human analog of the visual sensor was derived. An examination of the human analog of the eye disclosed that it is the symbolic representation of biological function of vision.

Table 1

Subsystems of Man

Input	Distribution and Control	Output
Visual	Nervous	Musculo-Skeletal (Movement and Speech)
Auditory	Endocrine	Skin (Sweat, Flakes and Thermal)
Gustatory	Small Intestine (Digestion)	Excretory
Olfactory	Cardiovascular	Reproductive
Tactile		
Radiation		
Respiration		
Upper G. I. Tract (Entering food for digestion)		

2.2 OUTLINE OF THE PHYSIOLOGY AND ANATOMY OF THE EYE

In order to gather the facts that would be used in assembling the human analog of the selected input subsystem, a review of the anatomy and physiology of the eye was conducted. Initial study enabled the anatomical boundaries of the visual sensor to be described as well as allowing the spacial relationships of the parts of the eye to be developed. By performing an examination of the eye, the boundaries of this subsystem may be described (Figure 2). Five-sixths of the eye is bounded by the sclera, which is white and opaque. From the front of the eye, a portion of the sclera may be seen as the white of the eye. The sclera is composed of a tough inelastic fibrous material that forms the protective exterior coat of the eye. This coat maintains the shape of the eye and gives it an almost spherical form. An average eye can be contained within a one-inch sphere. The remaining one-sixth sphere not covered by the sclera is protected by the cornea.

Anteriorly (toward the front of the skull) the eye is bounded by the cornea. This coating is made of material that is very similar to that found in the sclera, but in the cornea the fibers are transparent to a specific band of electromagnetic radiation (203 mμ to at least 3000 mμ,[1] 1 mμ = 10^{-9} meter). Thus, the cornea acts as a frequency filter.

The cornea is also one of the components in the eye that refracts light and thus brings it to focus on the retina. The normal eye has a focusing power of 60 diopters. A diopter is the reciprocal

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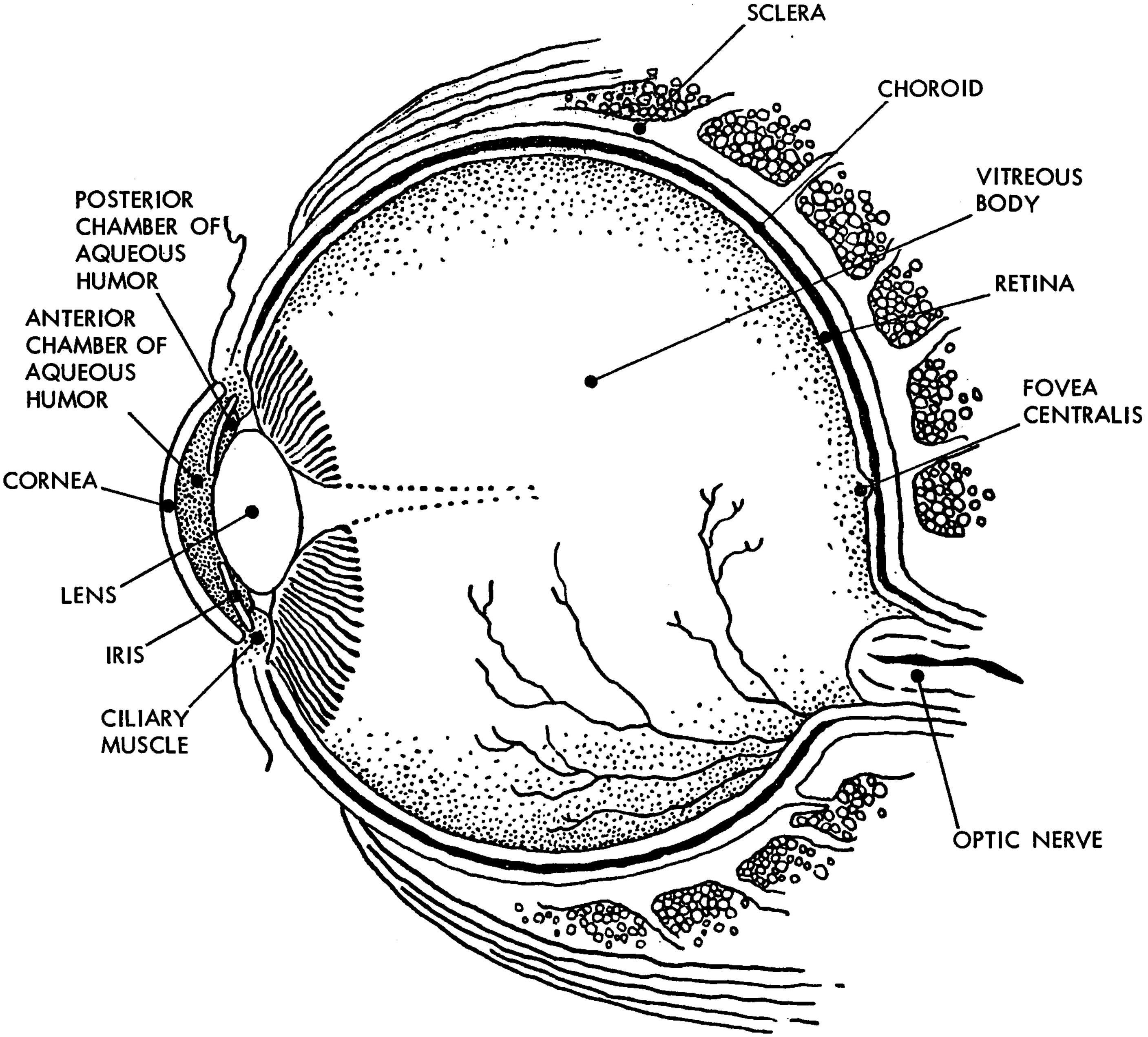
[1] Francis Heed Adler, Physiology of the Eye, Third Edition, 1959, p. 498.



(SOURCE, ATLAS OF HUMAN BODY, FIFTH EDITION, BARNES AND NOBLE, P - 138, 1959)

COMPONENTS OF THE EYE

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Figure 2

of the focal length in meters. Focusing power is directly proportional to the differential in refractive indices between media. Air has a refractive index of 1.000 while the entire eye can be considered to have an index of 1.33 which is the same index as water. Comparatively there is a large differential in refractive index between air (1.000) and the cornea (1.376). This large difference means that the air-cornea interface has the greatest refractive power found in the eye. In fact, the cornea contributes about 40 diopters of the total power of the eye.[1]

Less bending of light takes place at the cornea-aqueous humor interface since the refractive index differential is small (1.376 for cornea and 1.336 for aqueous humor). The aqueous is 99% water containing dissolved salts. Composition of this fluid is quite similar in most respects to blood plasma and to the virteous humor. Sometimes the entire aqueous humor is called the anterior chamber (as opposed to vitreous body which is posterior), but this name can be confusing since the liquid is anatomically separated into two areas that are called the posterior and anterior chambers. These chambers are divided by the iris.

Physiologically the iris controls the amount of light entering the eye. Control is conducted by regulating the diameter of the pupil. The muscle that regulates this diameter is directed by information received in the retina since there are no light receptors in the iris. Immediately posterior to the pupil of the iris is the lens (refractive index 1.4). The function of the lens is to focus entering

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1. J. D. Spooner, Ocular Anatomy, 1957, p. 13

light on the retina. As in the iris, the lens has no light receptors that can detect the focus of light on the retina. Thus the signals to control the muscles of the lens must originate from the retina. These muscles change the curvature of the lens and therefore influence the refraction of light rays.

Light that leaves the lens is transmitted through the vitreous body. This body contains a transparent gel that is called the vitreous humor and is similar to raw egg white. Chemically the vitreous and aqueous are similar. Both have approximately the refractive index of water and both apply pressure to their surroundings.

In the posterior direction, the vitreous humor exerts pressure on the retina. The retina may best be viewed as a location for many components of the eye and not as a functional unit. This lining is not completely transparent because light must traverse the 0.1 mm thickness of the retina to be absorbed in the posterior surface. Light that is not taken in by the retina strikes the choroid.

Functionally the choroid acts to absorb all incident rays so that no reflected light is allowed to stimulate the receptors. For this purpose, the choroid is black. The choroid lines the entire posterior half of the eye except where pierced by the optic nerve. This lining is in contact with the sclera in the posterior direction while anteriorly contact is made with the pigment epithelium layer of the retina.

Many dome-shaped cells compose the pigment epithelium. Near the cell boundaries a pigment called fuscin is concentrated. This pigment has an absorption band from 397 to 723 mμ which covers the visible range.[1] Throughout this range, the fuscin absorbs photons and transfers energy to the photochemical substances in the light receptors that are in contact with the pigment epithelium (Figure 3). The two types of receptors in the eye are called rods and cones because of their respective shapes. Rods contain a photochemical called rhodopsin.

2.2.1 Rhodopsin

The photochemical rhodopsin, sometimes referred to as visual purpole, is concentrated at the rod surface. Visual purple is a very complex organic compound that has an atomic weight that is quoted from 46,000[2] to 270,000.[3] The two basic components of rhodopsin are the chromophore, retinene_1, and the protein, scotopsin. The number of chromophores per protein molecule is not known, and estimates range from one to ten. A chromophore is that portion of a photochemical that selectively absorbs part of the visible spectrum. In rhodopsin the chromophore is called retinene_1, which has the formula $C_{19}H_{27}CHO$. Iodopsin contains retinene_1 and a protein called photopsin.

Molecules of retinene_1 and protein allow their free electrons to mutually interact to construct single covalent bonds between each adjacent atom as well as to build π-orbitals. These

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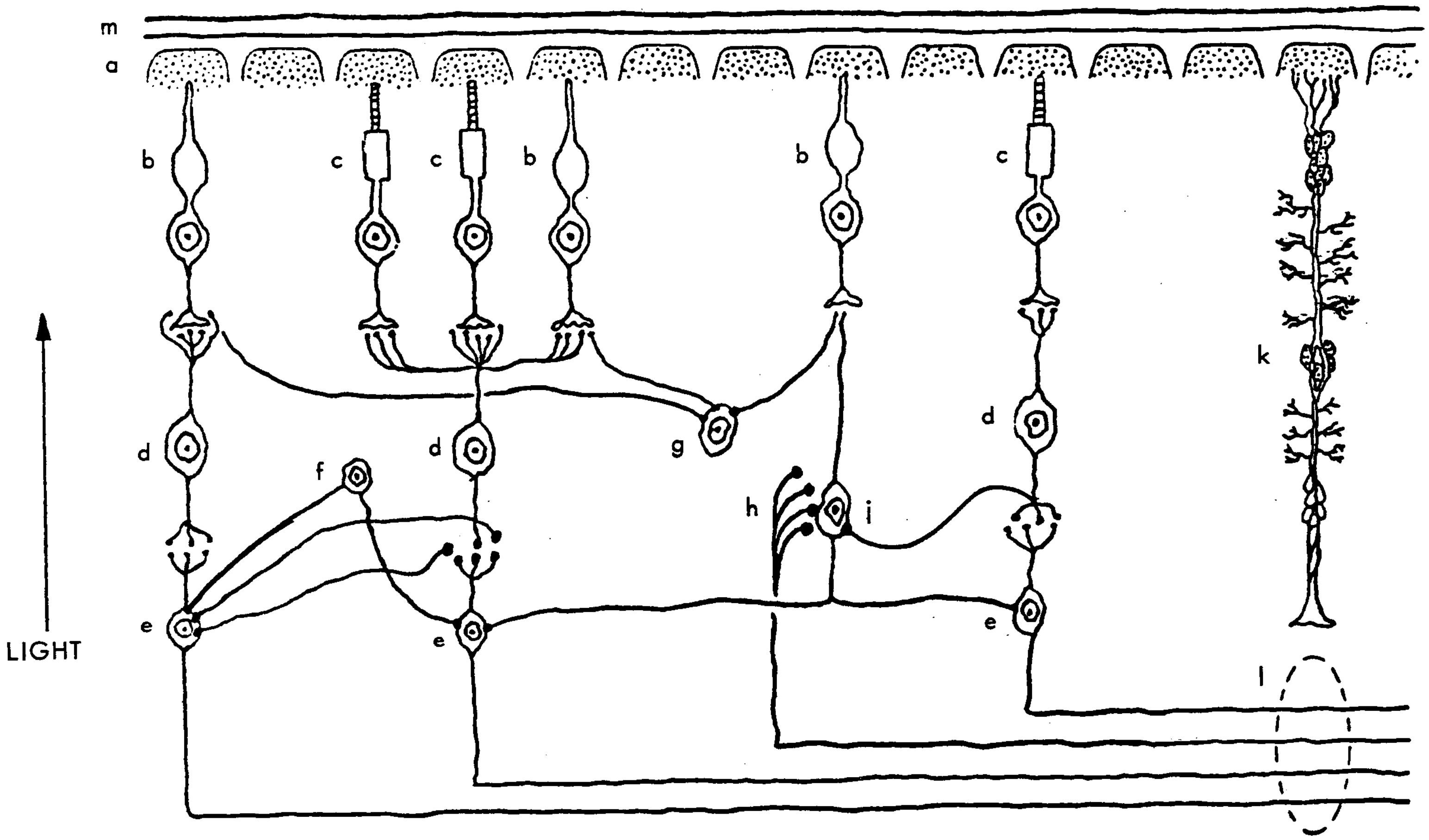
[1] John F. Fulton, A Textbook of Physiology, Seventeenth Edition, 1955, p. 446.

[2] Hamilton Hartridge, Recent Advances in the Physiology of Vision, 1950, p. 345.

[3] Ibid, p. 38.



THE RETINA

a PIGMENT EPITHELIUM
b CONE
c ROD
d CENTRIPETAL BIPOLAR CELL
e GANGLION CELL
f AMACRINE CELL
g HORIZONTAL CELL
h CENTRIFUGAL FIBER
i CENTRIFUGAL BIPOLAR CELL
k MULLER FIBER
l OPTIC NERVE
m CHOROID

(SOURCE: J.D.SPOONER, OCULAR ANATOMY,p.45-1957)

TSC 2219P

Figure 3. The Retina

orbitals are formed by the excess electrons that are not part of the covalent bonds and extend over the whole length of the conjugated chain. In the unexcited state the electrons occupy orbitals of the lowest energy; when absorption of light quanta takes place, the electrons enter orbitals of higher energy.[1]

"The oscillating electric vector of light causes the π-electrons to congregate backwards and forwards along the conjugated chain, first at one end and then at the other. When the light is of the proper frequency to correspond with the rhythm of these oscillations, it is strongly absorbed (the fundamental band in the visible)."[2]

The fundamental band defines the wavelength of the absorption maximum (symbolized as λ max.). This parameter is used because the only known way of characterizing a visual pigment is to measure its light absorbing properties. When the chromophore of rhodopsin absorbs a quantum of energy, the rise in electronic levels causes a change in the configuration of the chromophore so that it releases the protein and dissociation takes place. This causes the electric tension between chromophore and protein to disappear.

2.2.2 Rhodopsin Cycle

Perhaps the best method of explaining the chemical changes that rhodopsin undergoes is to present the complete cycle that this photochemical undergoes and then give the necessary details. Figure 4 is a diagram of the rhodopsin cycle.

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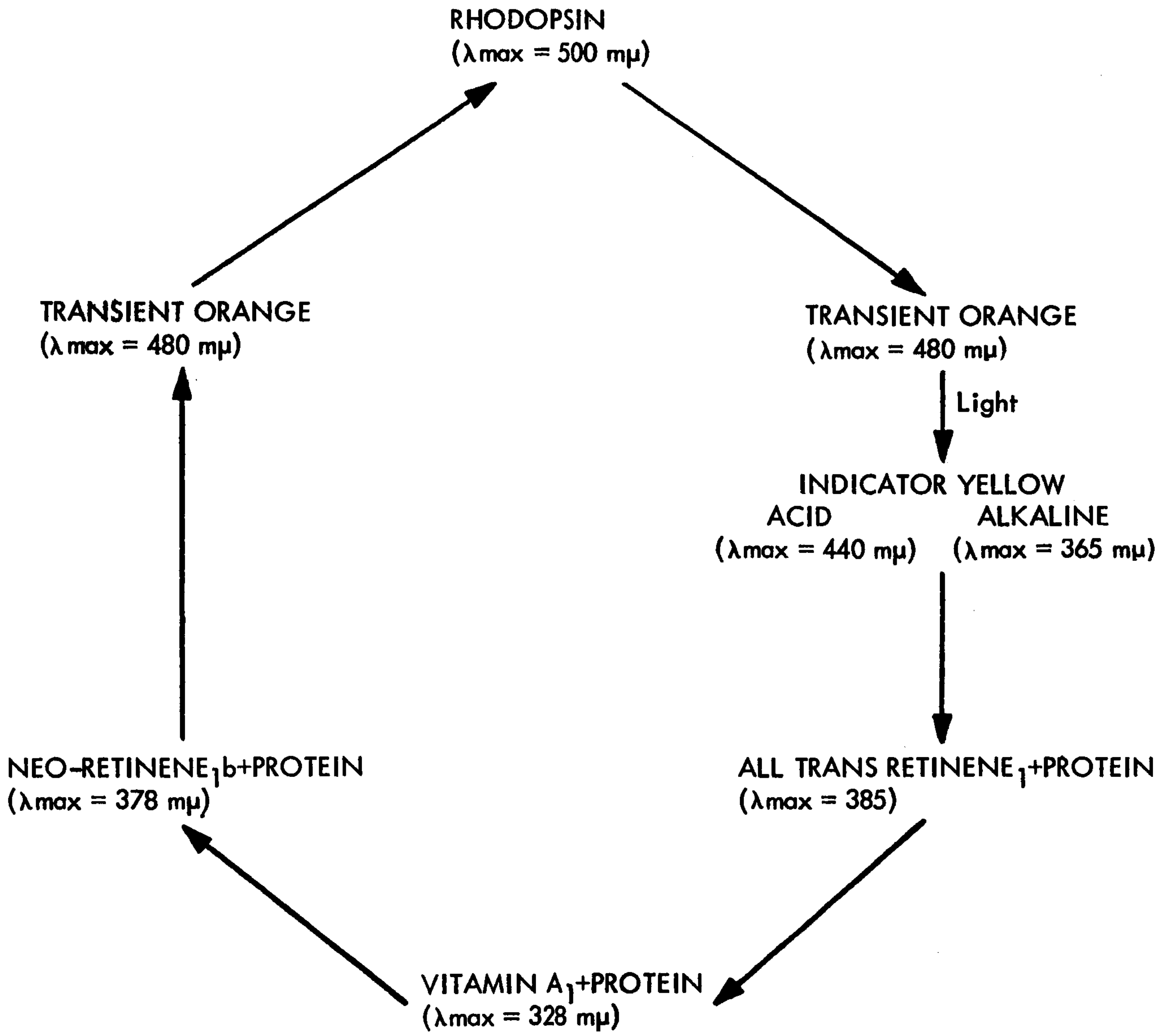
[1] H. J. A. Dartnall, The Visual Pigments, 1957, p. 37.
[2] Ibid, p. 101.



RHODOPSIN CYCLE

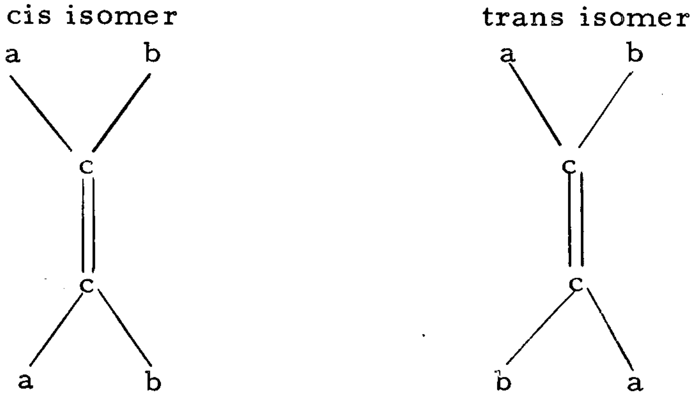
(ADAPTED FROM DARTNALL, THE VISUAL PIGMENTS, 1957, PAGE 54 AND 152)

TSC 3344

Figure 4

Even before exposure to light, rhodopsin can form transient orange. At room temperature, transient orange has a very short life, and in the presence of light is converted to indicator yellow, which is the first stable decomposition product of rhodopsin. In an acid (pH 5. 2) solution, the indicator is bright yellow, while in a base (pH=9-9. 5), the chemical is nearly colorless.[1]

Indicator yellow is composed of the chromophore retinene_1 and a protein. The configuration of indicator yellow is shown in Figure 5 . If thermal energy is given to indicator yellow, there is decomposition into all trans retinene_1 and protein. All trans retinene_1 is the isomer of the chromophore retinene_1 that involves the least strain. Retinene_1 occurs in two types of isomers, cis and trans. The basic difference between cis and trans isomers is shown in Figure 6 .



Isomers of Chromophores

(Dartnall, The Visual Pigments, 1957, Page 127)

Figure 5

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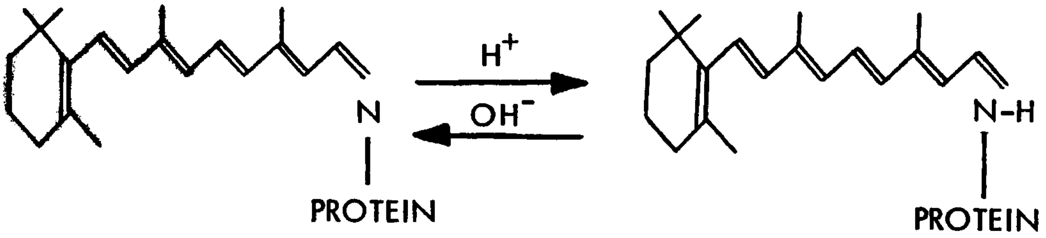
1. Ibid., p. 52.



ALKALINE INDICATOR YELLOW
($\lambda max = 365$ mμ)

ACID INDICATOR YELLOW
($\lambda max = 440$ mμ)

ALKALINE AND ACID FORMS OF INDICATOR YELLOW
(DARTNALL, THE VISUAL PIGMENTS, 1957, PAGE 109)

Figure 6

TSC 3343

All trans retinene$_1$ has the configuration shown in Figure 7 . The cis isomer will be encountered in the discussion of the resynthesis of rhodopsin. By thermal and enzymic action, all trans retinene$_1$ is converted to vitamin A$_1$. The protein molecule is still present and is not bonded to the vitamin A$_1$. The shorthand structural formula for vitamin A$_1$ is shown in Figure 8 .

Vitamin A$_1$ is the final chemical formed in the decomposition phase of rhodopsin. This phase of the rhodopsin cycle takes place when light impinges on the photoreceptors. An environment of darkness is required to allow the regeneration of visual purple to take place. It has been found that the photoreceptors must be in contact with the pigment epithelium to allow rhodopsin to regain its color in darkness, but this contact is not necessary during the bleaching of the photochemical.[1] This observation brings up the question of how the pigment epithelium influences the regeneration process.

Microscopic examination has disclosed that the pigment epithelium has processes that project like bristles from a brush and lie in the spaces between the photoreceptors. The processes contain pigment in granular and spindle form.[2] During regeneration the outer segment of the cone photoreceptors have been observed to lie in contact with the processes of the epithelium and to directly absorb pigment granules.[3] These granules very likely take part in the photochemical cycle that is carried out by the cones. Though

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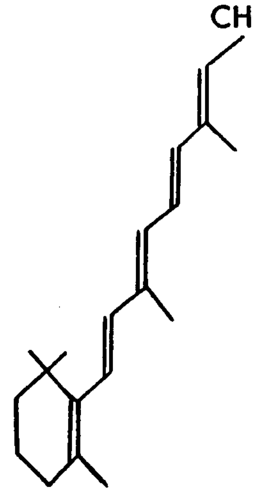
1. Dartnall, p. 26.
2. R. J. Last, Anatomy of the Eye and Orbit, 1961, p. 94.
3. *Ibid.*, p. 97.

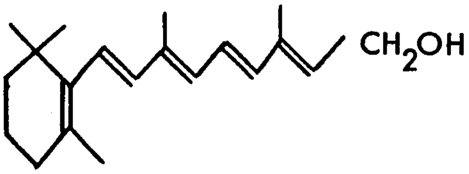


ALL TRANS RETINENE$_1$

$C_{19}H_{27}\cdot CHO$

($\lambda max = 385$ mμ)

Figure 7 TSC 3340



VITAMIN A$_1$

$C_{19}H_{27}\cdot CH_2OH$

($\lambda max = 328$ mμ)

Figure 8 TSC 3341

not yet observed for the rods, a similar exchange of pigment granules probably is carried out by the second type of receptor. To date the importance of this phenomenon in the photochemical cycle has not been explained.

Laboratory tests indicate that regeneration can be started by introducing alcohol dehydrogenase that acts as a catalyst in the oxidation of vitamin A_1 to neo-retinene$_1$ b, which is a cis isomer of retinene$_1$.[1] Figure 9 illustrates the configuration of neo-retinene$_1$ b. A spontaneous energy releasing reaction takes place in which neo-retinene$_1$ b and protein recombine to form the original photochemical. It is not clear if the retinene$_1$ protein recombination or the readjustment in the configuration of the protein accounts for the excitation that rhodopsin produces.[2] In either case, the recombination of the neo-retinene$_1$ b and protein completes the rhodopsin cycle.

2.2.3 Other Components of the Retina

The photochemical rhodopsin is located in the rods and is broken down even in dim light and thus makes night vision possible. Rods have another characteristic that makes them especially adept for seeing in little light. This characteristic is that frequently the effect of many rods are summed to stimulate one centripetal bipolar cell. Centripetal cells are sometimes referred to as the primary neurons, since they are the first cells to be stimulated by the receptors. See Figure 3 .

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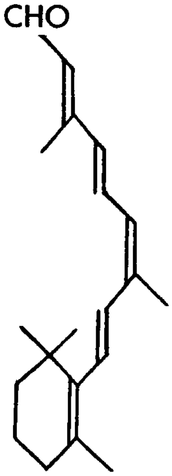
[1] Dartnall, p. 136.

[2] Adler, p. 522.



THREE CIS NEO-RETINENE$_1$ b
$C_{19}H_{27}\cdot CHO$
($\lambda max = 378$ mμ)

TSC 3342

Figure 9

Though rods give excellent night vision, in bright light, all of the rhodopsin breaks down simultaneously, and the receptors become ineffectual. Now the cones, which are the other type of light receptor, begin operating. Cones contain the photochemical iodopsin and are found throughout the retina. In the central portion of the retina, which is the fovea, the cones are the only receptors. Generally, one cone stimulates only one centripetal bipolar cell and thus gives more detailed and distinct vision than the rods because spacial integrity is maintained. Centripetal bipolar cells stimulate the secondary neurons called ganglion cells. The axons of the ganglion cells comprise the optic nerve. Interconnections between receptors, centripetal bipolar cells, and ganglion cells are made by association cells.

Association cells include the following: amacrine, centrifugal bipolar, horizontal, and centrifugal fibers. Amacrine cells are in reversed position with respect to the rest of the retina since they face the ganglion cells. An association between ganglion cells and possibly the centripetal bipolar cells is provided by the amacrine cells. This association may be in either direction because amacrine cells are not bipolar and have no axons. See Figure 3 for a drawing of the retina that shows the spacial relationships of the above named components.

An association cell that has both axons and dendrites is the centrifugal bipolar cell which is closely related to the amacrine cell. Centrifugal cells receive impulses from bipolar cells, ganglion cells, and centrifugal fibers. These impulses zre then transmitted to the receptors. Centrifugal fibers are derived via the optic nerve from the brain. It is possible that the brain sends inhibition and facilitation information to the neurons in the retina by means of the centrifugal fibers.

Another type of association cell present in the retina is the horizontal cell that electrically ties the rods and cones together. Horizontal cells transmit electric pulses to receptors that are as far as 1 mm away. This distribution of pulses gives spacial induction. Beside association cells, there are neurogolical cells in the retina. The major neurological cell is the Muller fiber that electrically insulates the neurons and holds them a controlled distance apart.

2.3 SUBSYSTEM LEVEL APPLICATION OF THE MAN-MACHINE METHODOLOGY TO THE ANALYSIS OF THE OPERATION OF THE HUMAN EYE

Prior to examining the analysis of the Operation of the Human Eye, it is suggested that the reader, who is not familiar with the techniques of the Man-Machine Methodology, refer to the final report under Contract NASw-567, which explains the Methodology in detail.

In the analysis that follows, a number of files are presented[1] that individually refer to specific intersections on the Subsystem Matrix Charts, pages 31 and 40. A file receives the parts of its complete numerical designation from three factors: 1 - Its level in the Hierarchy, 2 - Row number of intersection on matrix chart, and 3 - Column number of intersection on matrix chart. The levels of the Hierarchy are given in Table 2.

Table 2

Levels of the Hierarchy

Number	Level
1	Mission
2	System Complex
3	System
4	Subsystem
5	Component
6	Chemical
7	Physics

---

[1] The files presented in this final report represent only a selected portion of the intersections that were examined in the first quarterly report. The files contained in this report were selected because they illustrate the mechanics of operation of the Methodology.

An example of a file number is 4-111-01. As Table 2 indicates, the four (4) represents the Subsystem Level. From the Subsystem Level Matrix on page 40 , it can be seen that the row numbered 111 denotes the Influencing Factor of Configuration and the aspect called Parts. Finally column 01 symbolizes Man, Input, Sensory, Visual. Thus, each file is numbered by consideration of its hierarchial placement and intersection on a matrix chart.

Data contained in each file is recorded on Environment, Function, Configuration, and Material Information Sheets as well as on drawings. The first pages of each file contain a discussion of the steps taken to fill out the Information Sheets. Next, a Subsystem Matrix Chart is presented that has the intersection under consideration blacked-in. Intersections that have been previously examined are outlined on the Matrix Chart. Following this chart, the Information Sheets and their attendant drawings will be found.

File No: 4-05-01, Environment Information

Guide to Information Sheets

On beginning to apply the Methodology to the analysis of the operation of the human eye, the matrix charts were scanned to find the level that contained the visual sensor as an element. From the missions level, which is the most general, this scanning continued until the subsystem level matrix level chart was encountered. The Subsystem Matrix Charts are on pages 31 and 40. The subsystem level chart lists the eye under the column man, input, sensory, visual. In tracing this column down, all the influencing factors were encountered.

The first influencing factor that must be considered is environment. For the eye, the environment factor chosen for initial consideration was radiation, electromagnetic, visible. This is the intersection 4(subsystem level), 05(visible aspect), 01(man, input, sensory, visual column). For this intersection, a file was prepared that contained all the applicable information sheets. (Environment, Function, Configuration, and Materials).

On the Environment Information sheet, page 32, the parameters that were required to define radiation in the visible spectrum were stated. These parameters are frequency and intensity. It was felt that no meaningful entry could be made under the heading "amount of normal frequency" because visible light is rather uniformly distributed over the spectrum; consequently, the minimum and maximum frequencies define the range of visible light. For the parameter of intensity, the normal, minimum and maximum frequencies were found and listed on this information sheet.

Next, the supplementary information sheet of function, page 33 was filled out. The Methodology required that the entries on this sheet at the subsystem level be made with respect to the entire eye omitting reference to any of its components. The first column on this sheet asked for a statement of the functional aspect of the entire eye. To find this statement, the general aspects of function on the subsystem level matrix chart were scanned. Since the eye is a sensory subsystem that brings information to the nervous subsystem, the general aspect of input data was chosen to fill the first column.

In the second column, the object that directs visible radiation to the eye must be stated. The form of the energy that strikes the eye is a spacial relationship of light. This spacial relationship emanates from the object which is a visible image.

The following three columns on the function information sheet are labeled parameter, property and characteristic. These columns, that describe the object, supply unwanted details in the explanation of the general function of the entire eye at the subsystem level, and these spaces are blank.

Under the "convert to" column, a statement was made about what the output portion of the eye - the optic nerve - transmits to the nerves subsystem. This column contains the information that electric pulses are transmitted to the nervous subsystem. The next column asked for the method of conversion. Here the question first arises as to how the conversion from visible light to electric pulses takes place. This question cannot be answered at the subsystem level because a discussion of chemical and atomic interactions is required. Thus only the general statement that light energy undergoes a conversion was made. A detailed analysis of the conversion will begin on the component level where chemical interactions can be discussed. The mechanism of conversion could not be stated at the subsystem level, but the operation was given. In observing the entire eye, the operation was seen to be the absorption of light energy.

The second supplementary sheet that was needed to describe the environment was the configuration form, page 34. In the first column of this form, there is space for the aspect. The subsystem level matrix chart lists the aspects of configuration. First the parts aspect was investigated in its relation to that portion of the human eye that was affected by visible radiation. For this aspect, each of the columns on the configuration information sheet was noted, and drawings were made to illustrate those areas that were pertinent to the environment influencing factor.

Under the column "Connection of Parts", the drawing called Components of the Eye in Visible Radiation Path, page 35, was called out. This drawing points out those parts of the eye that are affected by visible radiation. A portion of the retina is drawn in an inset. The inset shows those components that light impinges upon.

The column labeled "Environment Interface In" calls out drawing number 4-05-01-2. On this drawing there is a transverse section of the visual sensor. The boundary between the atmosphere and the eye is the outer membranous coating over the cornea. This is a liquid like layer that continuously cleanses the cornea. At this boundary, the eye first interacts with the visible radiation.

After the eye modifies the visible radiation, the information signal is transmitted to the nervous subsystem. The transmission takes place across the "Environment Interface Out", which is the next column on the configuration information sheet. Drawing 4-05-01-3 shows the interface out which is bounded by the optic nerve and the lateral geniculate bodies. These are the first neurons in the nervous subsystem to receive electric pulses from the eye. Each optic nerve fiber is related to five or six lateral geniculate neuron cells.

On this drawing, it will be noted that light must pass through a considerable portion of the retina before striking the photoreceptors (rods and cones). The light is filtered as it passes through the components of the retina. A question of function is posed by the configuration of the retina. Usually there is a reason for a specific placement of parts in nature. What is the purpose of the inverted retina? This question will be answered in the course of the analysis of the eye.

At this point, the next aspect of configuration was located on the subsystem matrix chart. The aspect is called support structure. For the eye the support structure is composed of the external muscles. Since there is no direct interaction of the support structure and the environment (visible radiation), this aspect was not considered further on the configuration information sheet. A similar situation exists for the configurational aspects called container, internal dynamics and external dynamics.

The final form encountered under the environment influencing factor was the Material Information sheet, page 38. On this sheet, a list of the components of the eye that are affected by visible radiation is required. The list was composed and included all of the parts that were illustrated on the drawing "Components of the Eye in Visible Radiation Path".

File No: 4-05-01

Four columns on the material information sheet are labeled: existence, availability, producibility and relative cost. These four terms relate to the synthesis of materials so they may be used in design. In the present case, an analysis of an existing subsystem (the eye) is being made, and thus consideration of these terms is not necessary.

						MAN																MACHINE																	
				SUBSYSTEM		INPUT								DISTRIBUTION CONTROL				OUTPUT				INPUT						DISTRIBUTION CONTROL				OUTPUT			INPUT				
						SENSORY																SENSORS																	
ENVIRONMENT						VISUAL	AUDITORY	GUSTATORY	OLFACTORY	TACTILE	RESPIRATORY	UPPER G.I. TRACT	RADIATION	CARDIOVASCULAR	ENDOCRINE	NERVOUS	SMALL INTESTINE	MUSCULO SKELETAL	SKIN	EXCRETORY	REPRODUCTIVE	RADIATION	MAGNETIC	ELECTRO-STATIC	FORCE	CHEMICAL	POWER	POWER CIRCUITS	CONTROL CIRCUITS	INFORMATION HANDLING	HEAT & WASTE DISSIPATION	ACTUATORS	DISPLAYS	RADIATION	RADIATION	MAGNETIC	ELECTROSTATIC	FORCE	CHEMICAL
				TYPE	01	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
RADIATION	ELECTROMAGNETIC			ELECTRIC	02																																		
				RADIO	03																																		
				INFRA-RED	04																																		
				VISIBLE	05	■																																	
				ULTRA-VIOLET	06																																		
				SOFT X-RAY	07																																		
				HARD X-RAY	08																																		
				GAMMA	09																																		
	COSMIC			PROTONS	10																																		
				NEUTRONS	11																																		
				ELECTRONS	12																																		
FIELDS				MAGNETIC	13																																		
				ELECTROSTATIC	14																																		
FORCE				SUPER GRAVITY	15																																		
				EARTH GRAVITY	16																																		
				SUB GRAVITY	17																																		
				ZERO GRAVITY	18																																		
				ACCELERATION	19																																		
				VIBRATION	20																																		
				ACOUSTICS	21																																		
				PRESSURE	22																																		
MATTER	NON-LIVING	INORGANIC	ELEMENTS	HYDROGEN	23																																		
				LIGHT METALS	24																																		
				HEAVY METALS	25																																		
				NON-METALS	26																																		
				INERT GASES	27																																		
				RARE EARTHS	28																																		
			COMP-OUNDS	ACIDS	29																																		
				BASES	30																																		
				SALTS	31																																		
		ORGANIC		ALKANES	32																																		
				ALKENES	33																																		
				ALKYNES	34																																		
				ALKADIENES	35																																		
				AROMATICS	36																																		
	LIVING	ANIMAL		PORIFERA	37																																		
				COELENTERATA	38																																		
				CTENOPHERA	39																																		
				PLATYHELMINTHES	40																																		
				NEMATHELMINTHES	41																																		
				ECHINODERMATA	42																																		
				MOLLUSCA	43																																		
				ANNELIDA	44																																		
				ARTHROPODA	45																																		
				CHORDATA	46																																		
				MAN	47																																		
		PLANT		MYXOPHYTA	48																																		
				CLOROPHYTA	49																																		
				CHRYSOPHYTA	50																																		
				PHACOPHYTA	51																																		
				RHODOPHYTA	52																																		
				MYCOPHYTA	53																																		
				BRYOPHYTA	54																																		
				TRACHEOPHYTA	55																																		
		MICRO-ORGANISMS		SCHIZOMYCETES	56																																		
				MASTIGOPHORA	57																																		
				SARCODINA	58																																		
				SPOROZOA	59																																		
				CILIOPHORA	60																																		
				MYXOMYCETES	61																																		
	PARTICLES			SKIN	62																																		
				HAIR	63																																		
				DUST	64																																		
				LINT	65																																		
				FLAKES	66																																		
	ANIMAL BY-PRODUCTS			FECES	67																																		
				URINE	68																																		
				SWEAT																																			
				GASES																																			
				SEMENAL																																			
				THERMAL																																			

This sheet is only a portion of the entire Subsystem/Environment Matrix sheet.

ENVIRONMENT INFORMATION

FILE NO.: 4-05-01

ELEMENT: Man, Input, Sensory, Visual

UNIT OF RATE OF CHANGE:

DEFINITION / ENVIRONMENT	PARAMETER	QUANTITY								RATE OF CHANGE					
		NORMAL		MINIMUM		MAXIMUM		RATE OF NORMAL INCIDENCE		NORMAL		MINIMUM		MAXIMUM	
		AMT	DUR	AMT	DUR	AMT	DUR	AMT	TIME	AMT	DUR	AMT	DUR	AMT	DUR
EARTH	Frequency (cps)*	--	--	4.3×10^{14}	∞	7.56×10^{14}	∞								
	Intensity (candle power)	50	8 hr (in office)	0	8 hr (in sleep)	10,000 (Full sun)	--								
LUNAR															
SPACE															
PLANETARY															

* Source of data: John F. Fulton, A Textbook of Physiology, page 446, 1955

TSC 1640

FUNCTION INFORMATION

FILE NO: 4-05-01

ELEMENT: Man, Input, Sensory, Visual

DEFINITION / FUNCTION	OBJECT	PARA-METER	PROPERTY	CHARACT-ERISTIC	CONVERT TO	METHOD	METHOD SUB-DETAIL NO.1	METHOD SUB-DETAIL NO.2	MECH-ANISM	OPERATION	OPERATION SUB-DETAIL NO.1	OPERATION SUB-DETAIL NO.2	CHANGE WHEN TOLERABLE LIMITS ARE EXCEEDED
ASPECT: Input Data	visible image				electric pulses	conversion of light energy				absorption of light energy			

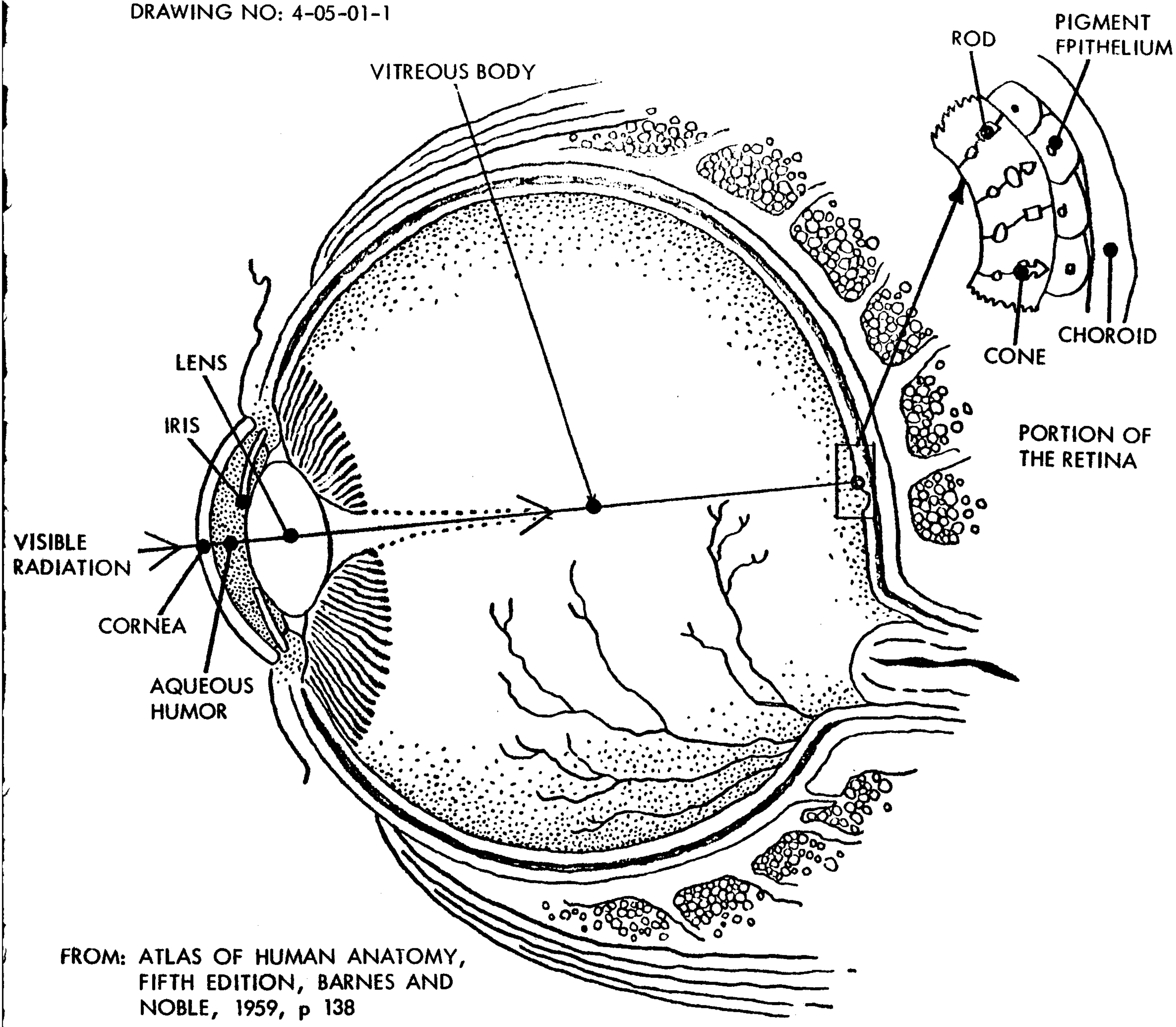
CONFIGURATION INFORMATION

FILE NO.: 4-05-01

ELEMENT: Man, Input, Sensory, Visual

DRAWINGS CONFIGURATION ASPECT:	ARRANGEMENT OF PARTS	CONNECTION OF PARTS	DIMENSIONS	SHAPE	MOTION	DEGREES OF FREEDOM	ENVIRONMENT INTERFACE IN	ENVIRONMENT INTERFACE OUT	CHANGE WHEN TOLERABLE LIMITS ARE EXCEEDED
		Compo-					air -	optic	
Parts		nents of					cornea	nerve -	
		Eye in					Drawing	lateral	
		visible					No.	geniculate	
		Radiation					4-05-01-2	bodies	
		Path						Drawing	
		Drawing						No.	
		No.						4-05-01-3	
		4-05-01-1							

DRAWING NO: 4-05-01-1



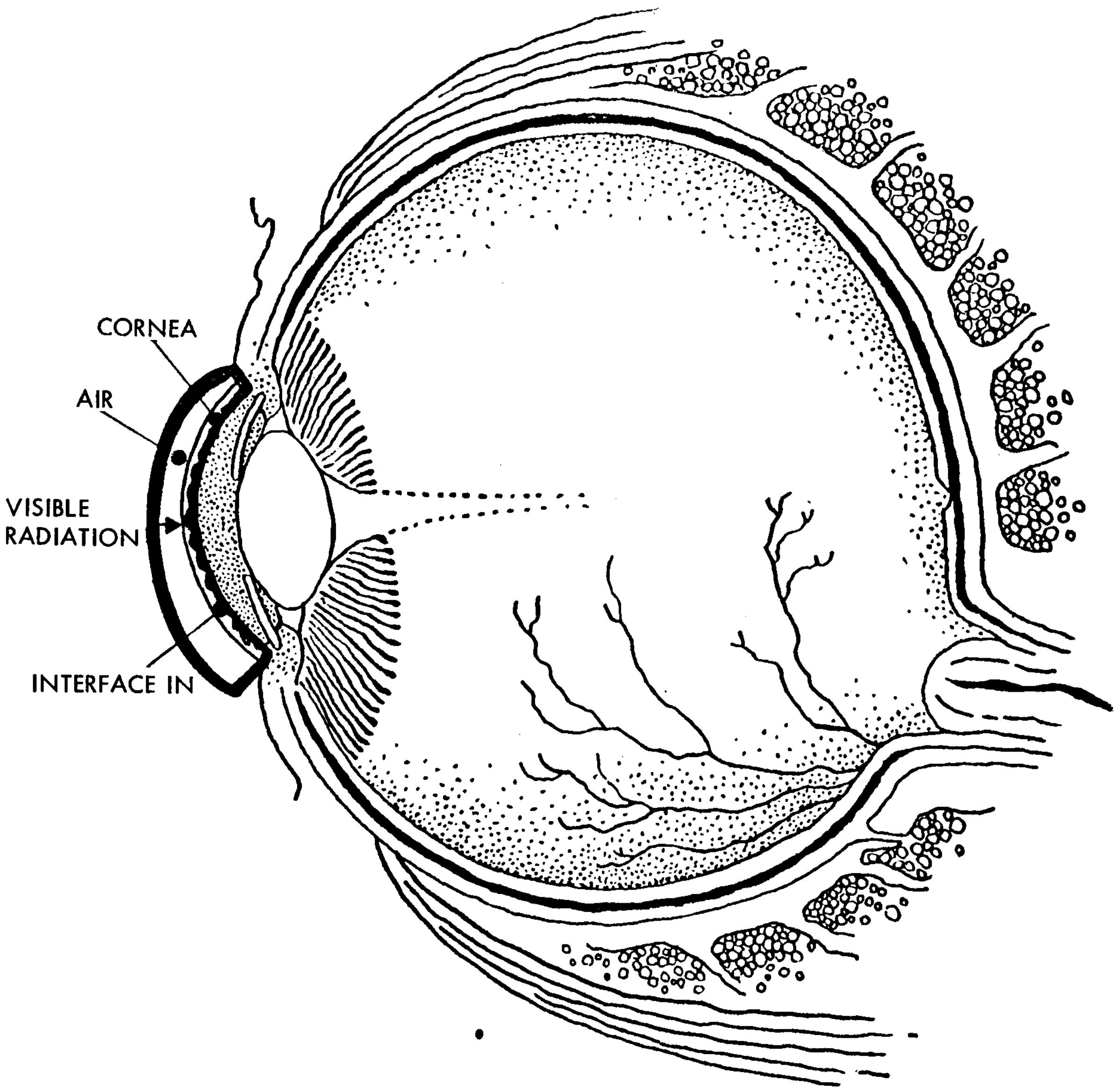
FROM: ATLAS OF HUMAN ANATOMY,
FIFTH EDITION, BARNES AND
NOBLE, 1959, p 138

COMPONENTS OF THE EYE IN VISIBLE RADIATION PATH
TRANSVERSE SECTION OF EYE
ENVIRONMENT INFLUENCING FACTOR

DRAWING NO: 4-05-01-1

TSC 2218A

DRAWING NO: 4-05-01-2

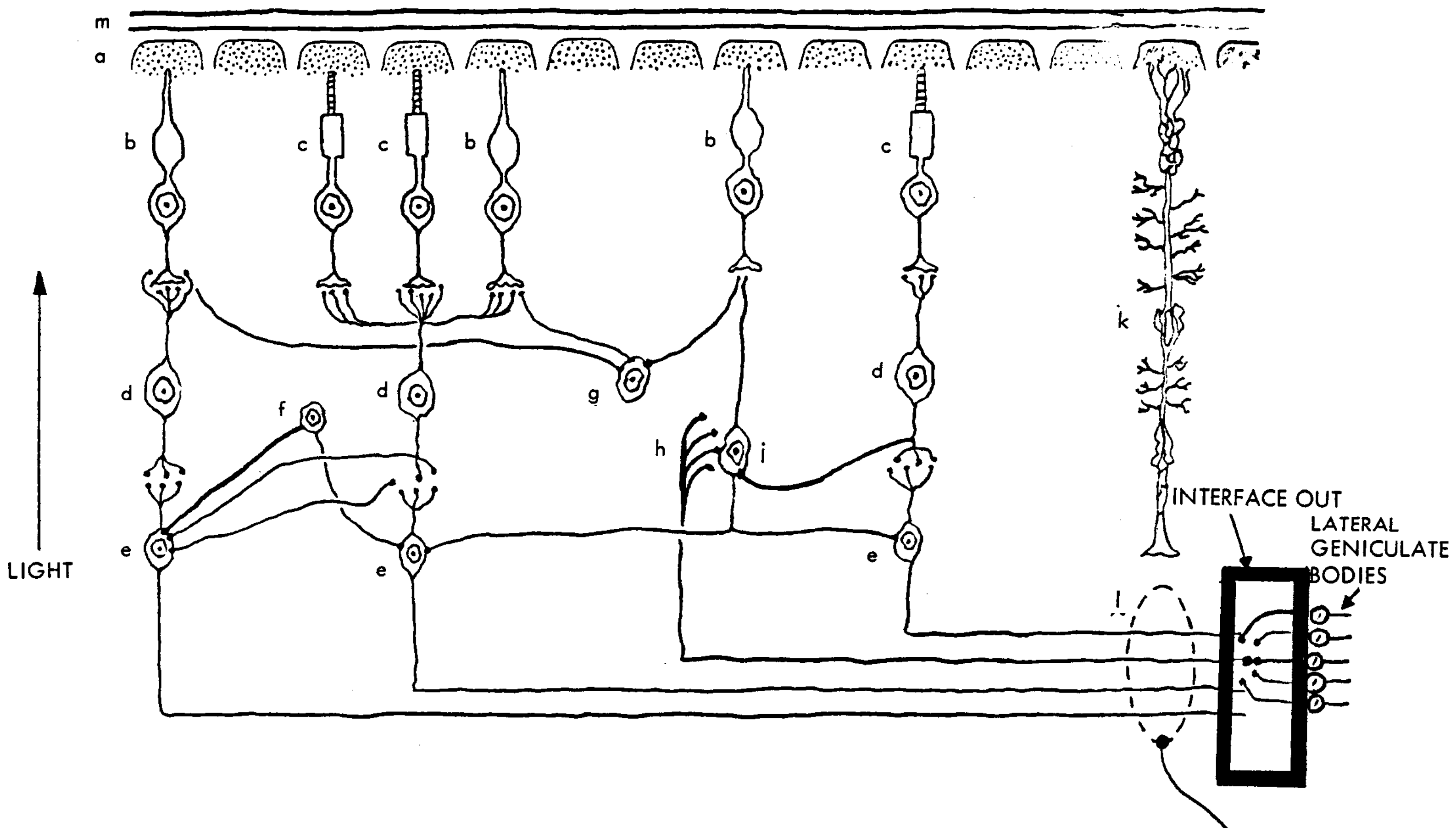


CONFIGURATION - INTERFACE IN
TRANSVERSE SECTION OF EYE
ENVIRONMENT INFLUENCING FACTOR

DRAWING NO: 4-05-01-2

TSC 2218B

DRAWING NO: 4-05-01-3



THE RETINA

a PIGMENT EPITHELIUM
b CONE
c ROD
d CENTRIPETAL BIPOLAR CELL
e GANGLION CELL
f AMACRINE CELL
g HORIZONTAL CELL
h CENTRIFUGAL FIBER
i CENTRIFUGAL BIPOLAR CELL
k MULLER FIBER
l OPTIC NERVE
m CHOROID

CONFIGURATION - INTERFACE OUT
ENVIRONMENT INFLUENCING FACTOR

DRAWING NO: 4-05-01-3

TSC 2219A

MATERIAL INFORMATION

FILE NO: 4-05-01

ELEMENT: Man, Input, Sensory, Visual

MATERIALS (next level) / MATERIALS	EXISTENCE	AVAILABILITY	PRODUCIBILITY	RELATIVE COST	REMARKS:
TYPE:					
cornea					
aqueous humor					
iris					
lens					
vitreous body					
choroid					
rods					
cones					
pigment epithelium					

TSC 1643

File No: 4-78-01

Guide to System Design Sheet

The first intersection that was encountered on the subsystem level matrix chart (shown on following page) under the function influencing factor was identified as 4-78-01. This intersection provided for a general functional breakdown of the entire eye into the segments of input, distribution and control, and output. A System Design sheet was used to present the "Major Components of the Eye".

There are two interfaces on the System Design sheet that require an explanation. The first is between the input and the distribution and control portions of the eye. It was hypothesized that electrons are transmitted between the rod and cone surface and the rod and cone proper. Between the distribution and control and the output portions, experimental evidence has verified that there is transverse ion flow.

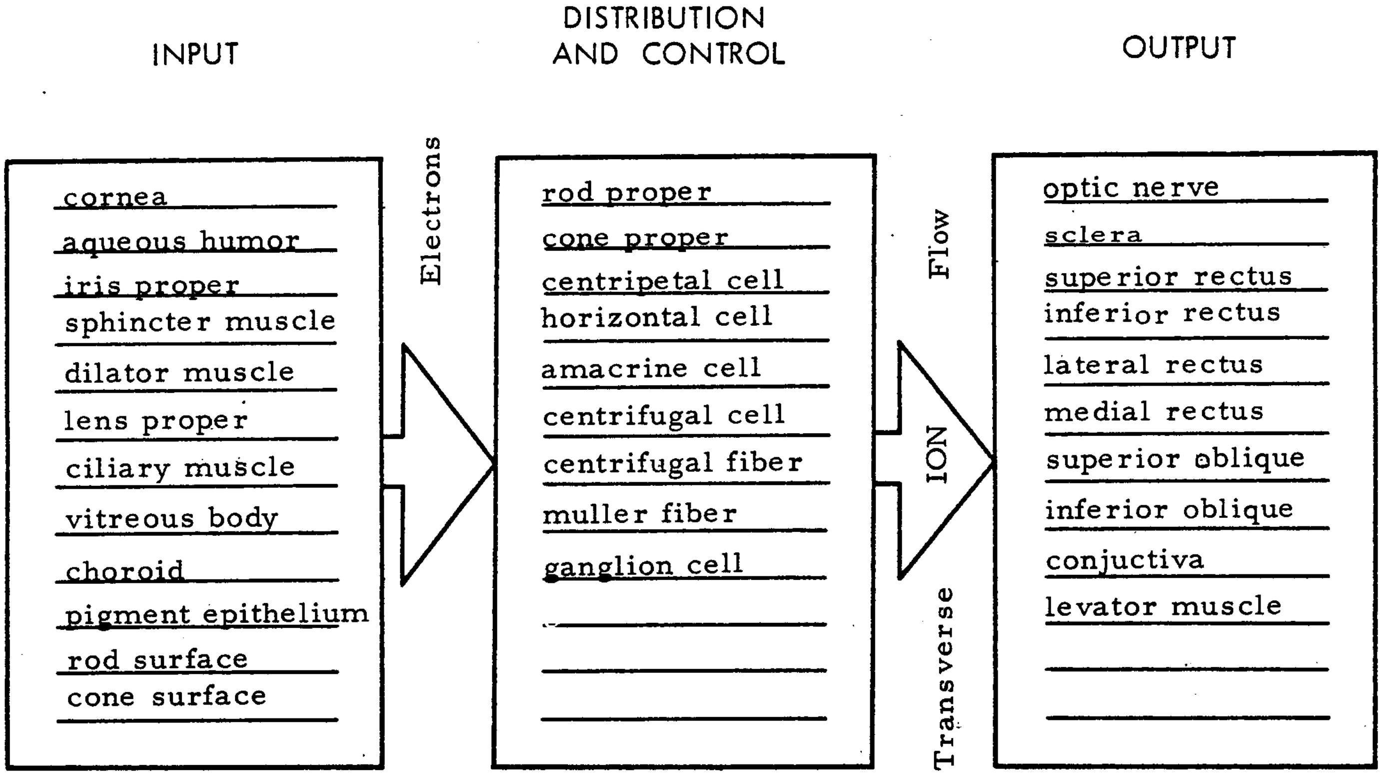
		SUBSYSTEM		MAN																MACHINE												
				INPUT								DIST. AND CONTROL				OUTPUT				INPUT						DIST. AND CONTROL				OUTPUT		
				SENSORY					RESPIRATORY	UPPER G.I. TRACT	RADIATION	CARDIOVASCULAR	ENDOCRINE	NERVOUS	SMALL INTESTINE	MUSCULO SKELETAL	SKIN	EXCRETORY	REPRODUCTIVE	SENSORS					POWER	POWER CIRCUITS	CONTROL CIRCUITS	INFORMATION HANDLING	HEAD AND WASTE DISSIPATION	ACTUATORS	DISPLAYS	RADIATION
		FUNCTION	(78)	VISUAL	AUDITORY	GUSTATORY	OLFACTORY	TACTILE												RADIATION	MAGNETIC	ELECTROSTATIC	FORCE	CHEMICAL								
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
INPUT	DATA	DETECT	79																													
		QUANTIZE	80																													
		QUALIFY	81																													
		TRANSDUCE	82																													
		DISCARD NOISE	83																													
		TRANSMIT INFO. SIGNAL	84																													
	POWER	ACQUIRE	85																													
		QUANTIZE	86																													
		QUALIFY	87																													
		CONVERT	88																													
		DISCARD WASTE	89																													
DISTRIBUTION AND CONTROL	DATA	ACCEPT INFO. SIGNAL	90																													
		ACCEPT INT. CONTROL SIGNAL	91																													
		CONVERT INFO. SIGNAL	92																													
		CORR. CONV. SIG. TO STORE	93																													
		CONV. STORED SIG. TO DEC.	94																													
		TRANSMIT DEC. SIGNAL	95																													
	POWER	ACQUIRE EXT. POWER	96																													
		ACCEPT INT. POWER	97																													
		CONVERT POWER TO STORE	98																													
		CORRELATE STORED POWER	99																													
		CONV.STORED POWER TO INPUT	100																													
		DISCARD WASTE	101																													
OUTPUT	DATA	ACCEPT DEC. SIGNAL	102																													
		CONVERT TO ACTION	103																													
		CORR. WITH STORE	104																													
		TRANSMIT ACTION SIG.	105																													
	POWER	RETRIEVE STORED POWER	106																													
		CONV. TO ACTION	107																													
		CORR. WITH STORE	108																													
		TRANSMIT ACTION	109																													
		SUBSYSTEM CONFIGURATION	110																													
		PARTS	111																													
		SUPPORT STRUCTURE	112																													
		CONTAINER	113																													
		INTERNAL DYNAMICS	114																													
		EXTERNAL DYNAMICS	115																													
		SUBSYSTEM MATERIALS	116																													
		ACCELERATABLE MASSES	117																													
		CONSTRAINED MASSES	118																													
		CHEMICAL CELLS	119																													
		RADATION SOURCES	120																													
		PERMANENT MAGNENTS	121																													
		ELECTRETS	122																													
		CONDUCTING LOOPS	123																													
		CONDUCTING SURFACES	124																													
		NON-CONDUCTORS	125																													
		SUBSYSTEM TASKS	126																													
			127																													
			128																													
			129																													
			130																													
			131																													
			132																													
			133																													
			134																													
			135																													
			136																													

This sheet is only a portion of the entire Subsystem/Function Matrix sheet.

SYSTEM DESIGN

FILE NO.:	ITEM	DWG NO.	ITEM	DWG NO.	ITEM	UNIT	AMT
4-78-01	SHAPE		SUPPORT STRUCTURE		DIMENSIONS		
	ARRANGEMENT		CONTAINER		VOLUME		
	CONNECTION OF PARTS				WEIGHT		

SYSTEM FUNCTIONAL BLOCK DIAGRAM



MAJOR COMPONENTS OF EYE

File No: 4-79-01, Input

On the sample subsystem level matrix chart, page 45 , the "78" is circled and the intersection 4-79-01 is blacked in. The outlined numeral indicates that intersection 78 has been previously considered, and the darkened square shows the intersection that is presently being investigated. Thus attention is drawn to the functional aspect of input, data, detect.

In the first column of the function information sheet, the aspect was recorded as detect. This aspect is a description of how the eye initially becomes aware that a visible image is directing radiation toward the visual sensor. The object asked for in the second column is the visible image which sends visible radiation to the eye. Visible radiation is the parameter of the object. Following parameter, the next column lists the properties of the visible radiation. These properties are frequency and intensity. The characteristic of frequency is given as periodicity.

Next, the "Convert To" column provides space to state the modified energy form of the object after detection has taken place. To fill in this column, an understanding must be obtained of what occurs in the eye when detection of visible radiation takes place. A search of the literature yielded no explanation of the detection function, and thus a hypothesis was made.

The hypothesis was developed by attempting to explain the interaction between visible radiation and materials of the eye that are affected by light. This hypothesis was formulated by explaining interactions between electromagnetic waves and atoms. A discussion of this type involves basic physics relationships, and thus the details of the hypothesis will be presented at a lower level of the Methodology. It is not necessary to become involved in these details at the subsystem level. All that need be said here is that the hypothesis is based on the phenomenon of resonance, and leads to the statement that radiation detection takes place by means of resonance.

When the resonance hypothesis is extended to the eye, structures can be found in the surface of the receptors that have a latent ability to resonante. This latent ability is utilized, and resonance is excited by the visible radiation that is striking the surface of the receptors.

Now the "Convert To" column could be filled out. The visible image transmits energy to the eye that is absorbed by resonance in some structure within the eye. Under "Method" the statement is made that there is an interaction of the electromagnetic field with the resonant structure and the method sub-detail no. 1 is concerned with the fact that forces are exerted on the resonant structure.

At the subsystem level, the mechanism could not be described, but the operation was stated. To explain the operation, it was noted that detection begins when visible radiation strikes the cornea and continues as transmission takes place through the eye. Finally the visible radiation penetrates the surface of the receptors (rods and cones); here absorption occurs - resonance takes place - and an energy conversion is brought about. The function of detection is completed by this initial energy conversion.

File No: 4-79-01

The Configuration Information sheet was next filled out. Only the Configurational aspect concerned with parts was considered because this is the one aspect that is involved in detection. Drawings were made to illustrate the process of detection as well as to show the anatomical parts of the eye concerned with this aspect.

A function schematic was drawn, Drawing 4-79-01-1. At the top of this drawing, the three steps in detection are shown, while the remainder of the illustration depicts those parts of the eye that carry out the process. Acceptance of visible radiation is shown to take place at the cornea and the transmission of the radiation is through the aqueous humor, lens and vitreous body. Finally resonance is excited in the receptor (rod and cone) surface. The cross sectional view of the receptors indicates that the surface,not the receptor proper,contains the resonant structure.

On Drawing 4-79-01-2, the Interface In is shown. This is the interface where the aspect of detection begins. The drawing indicates that the portion of the cornea that is exposed to the air is the Interface In.

The next drawing shows the Interface Out. This is Drawing 4-79-01-3. On this sheet a cross sectional view of a receptor is shown. The illustration indicates that the detection function is completed at the border of the receptor surface and receptor proper.

Listed on the Material Information sheet are those components of the eye that are involved in the detection of visible radiation.

		SUBSYSTEM FUNCTION	78	MAN																MACHINE												
				INPUT								DIST. AND CONTROL				OUTPUT				INPUT						DIST. AND CONTROL				OUTPUT		
				SENSORY																SENSORS												
				VISUAL	AUDITORY	GUSTATORY	OLFACTORY	TACTILE	RESPIRATORY	UPPER G.I. TRACT	RADIATION	CARDIOVAS-CULAR	ENDOCRINE	NERVOUS	SMALL INTESTINE	MUSCULO SKELETAL	SKIN	EXCRETORY	REPRODUCTIVE	RADIATION	MAGNETIC	ELECTRO-STATIC	FORCE	CHEMICAL	POWER	POWER CIRCUITS	CONTROL CIRCUITS	INFORMATION HANDLING	HEAD AND WAS-TE DISSIPATION	ACTUATORS	DISPLAYS	RADIATION
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
INPUT	DATA	DETECT	79	■																												
		QUANTIZE	80																													
		QUALIFY	81																													
		TRANSDUCE	82																													
		DISCARD NOISE	83																													
		TRANSMIT INFO. SIGNAL	84																													
	POWER	ACQUIRE	85																													
		QUANTIZE	86																													
		QUALIFY	87																													
		CONVERT	88																													
		DISCARD WASTE	89																													
DISTRIBUTION AND CONTROL	DATA	ACCEPT INFO. SIGNAL	90																													
		ACCEPT INT. CONTROL SIGNAL	91																													
		CONVERT INFO. SIGNAL	92																													
		CORR. CONV. SIG. TO STORE	93																													
		CONV. STORED SIG. TO DEC.	94																													
		TRANSMIT DEC. SIGNAL	95																													
	POWER	ACQUIRE EXT. POWER	96																													
		ACCEPT INT. POWER	97																													
		CONVERT POWER TO STORE	98																													
		CORRELATE STORED POWER	99																													
		CONV.STORED POWER TO INPUT	100																													
		DISCARD WASTE	101																													
OUTPUT	DATA	ACCEPT DEC. SIGNAL	102																													
		CONVERT TO ACTION	103																													
		CORR. WITH STORE	104																													
		TRANSMIT ACTION SIG.	105																													
	POWER	RETRIEVE STORED POWER	106																													
		CONV. TO ACTION	107																													
		CORR. WITH STORE	108																													
		TRANSMIT ACTION	109																													
		SUBSYSTEM CONFIGURATION	110																													
		PARTS	111																													
		SUPPORT STRUCTURE	112																													
		CONTAINER	113																													
		INTERNAL DYNAMICS	114																													
		EXTERNAL DYNAMICS	115																													
		SUBSYSTEM MATERIALS	116																													
		ACCELERATABLE MASSES	117																													
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		CHEMICAL CELLS	119																													
		RADATION SOURCES	120																													
		PERMANENT MAGNENTS	121																													
		ELECTRETS	122																													
		CONDUCTING LOOPS	123																													
		CONDUCTING SURFACES	124																													
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			134																													
			135																													
			136																													

FUNCTION INFORMATION

FILE NO: 4-79-01

ELEMENT: MAN, INPUT, SENSORY, VISUAL

DEFINITION / FUNCTION	OBJECT	PARAMETER	PROPERTY	CHARACTERISTIC	CONVERT TO	METHOD	METHOD SUB-DETAIL NO. 1	METHOD SUB-DETAIL NO. 2	MECHANISM	OPERATION	OPERATION SUB-DETAIL NO. 1	OPERATION SUB-DETAIL NO. 2	CHANGE WHEN TOLERABLE LIMITS ARE EXCEEDED
ASPECT: Detect	visible image	visible radiation	frequency and intensity	periodicity and amplitude	resonance in a structure	interaction of electromagnetic field with resonant structure	force on a structure			transmission absorption of visible radiation			

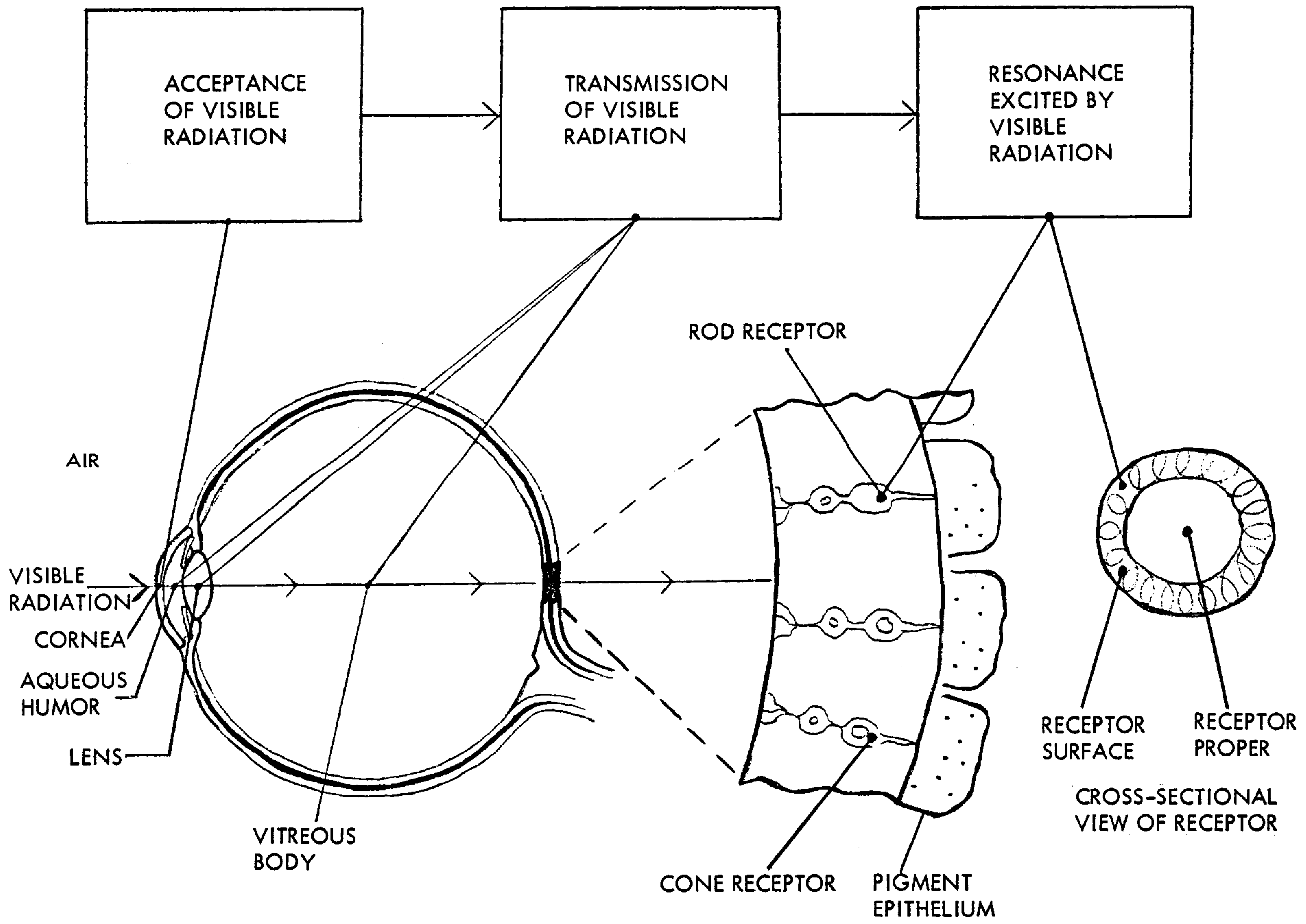
CONFIGURATION INFORMATION

FILE NO.: 4-79-01

ELEMENT: Man, Input, Sensory, Visual

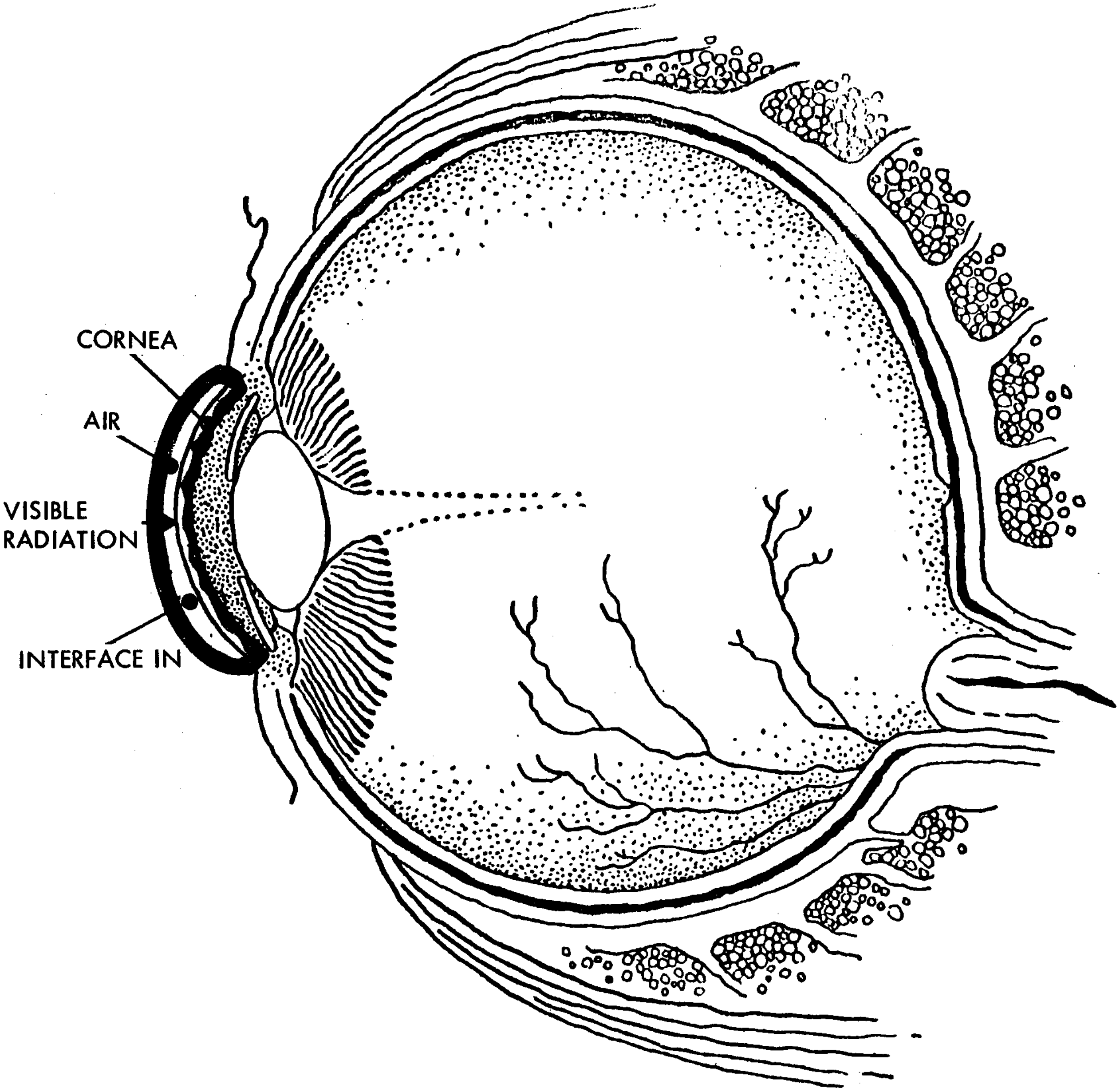
DRAWINGS CONFIGURATION ASPECT:	ARRANGEMENT OF PARTS	CONNECTION OF PARTS	DIMENSIONS	SHAPE	MOTION	DEGREES OF FREEDOM	ENVIRONMENT INTERFACE IN	ENVIRONMENT INTERFACE OUT	CHANGE WHEN TOLERABLE LIMITS ARE EXCEEDED
Parts		Detection					air-	receptor	
		Functional					cornea	surface-	
		Schematic					Drawing	receptor	
		Drawing					no:	proper	
		No:					4-79-01-2	Drawing	
		4-79-01-1						no:	
								4-79-01-3	

DRAWING NO.: 4-79-01-1



DETECTION FUNCTIONAL SCHEMATIC
TRANSVERSE SECTION OF EYE
CONFIGURATION - CONNECTION OF PARTS
DRAWING NO.: 4-79-01-1

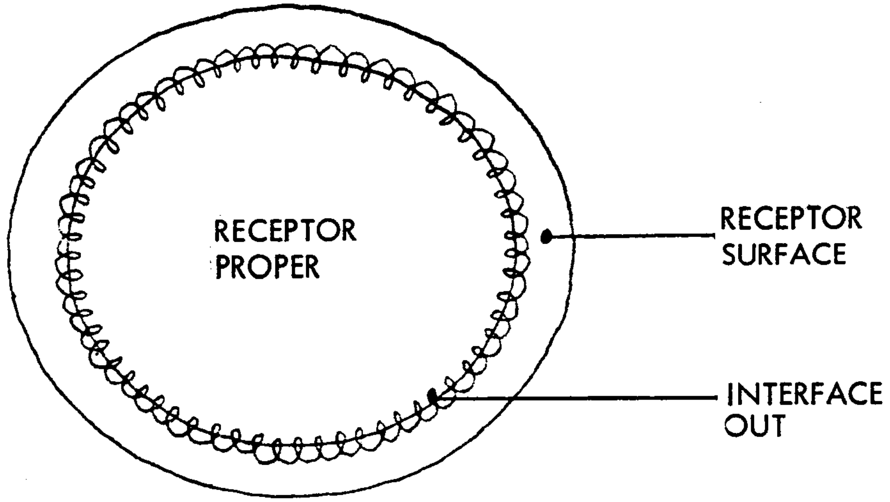
DRAWING NO: 4-79-01-2



CONFIGURATION - INTERFACE IN
TRANSVERSE SECTION OF EYE
DETECTION FUNCTION ASPECT

DRAWING NO: 4-79-01-2

TSC 2218C



CONFIGURATION - INTERFACE OUT
CROSS SECTION OF RECEPTOR
DETECTION FUNCTIONAL ASPECT
DRAWING NO.: 4-79-01-3

MATERIAL INFORMATION

FILE NO:
4-79-01

ELEMENT:
Man, Input, Sensory, Visual

MATERIALS (next level) / MATERIALS	EXISTENCE	AVAILABILITY	PRODUCIBILITY	RELATIVE COST	REMARKS:
TYPE:					
Cornea					Visible radiation
Aqueous humor					Transmitted by these components
Lens					
Vitreous humor					
Pigment epithelium					Visible radiation
Rod surface					absorbed by these components
Cone surface					

The function aspect of quantize includes an explanation of how the eye determines the amount of visible radiation present. In describing how the Function Information sheet was filled out, the column labeled Object will be discussed first. The Object is found by considering the function of detection which precedes quantization. As soon as the eye has detected the visible radiation, the quantization conversion may begin.

It will be necessary to continue with the resonance hypothesis to explain the quantization conversion that begins in the resonant structures of the surface of the receptors which is where the detection conversion terminates. In the column labeled Object, the energy of the resonant structure is listed.

There are a number of columns on the function sheet that are blank. These spaces could not be filled in on the subsystem level because the details involved are on the chemical and atomic levels.

When the energies absorbed by the resonating structures become large enough, electrons are dislodged from their bonds and flow from the receptor surface into the receptor proper. Thus the "Convert To" column indicates that the energy has been changed to the kinetic motion of electrons. The quantization is completed by this conversion because the energy of the electrons is in proportion to the activity of the visible radiation that is absorbed by the resonant structure.

There are a number of drawings called out on the Configuration Information sheet. The first is a functional schematic of quantization, Drawing 4-80-01-1. This illustration is similar in form to the functional schematic of detection that was previously discussed. The quantization conversion takes place in the receptor surface and produces electrons that are transmitted to the receptor proper.

On the following illustration, Drawing 4-80-01-2, the energy dissipation in the eye is shown. Prior to the energy conversion described, visible radiation is dissipated in the components of the eye. The drawing indicates the penetration of 100 quanta at the cornea, and the resulting energy in the parts of the eye.

Drawing 4-80-01-3 indicates that quantization of visible radiation begins at the cornea, while Drawing 4-80-01-4 shows that the quantization conversion ends at the interface between the receptor surface and receptor proper.

The Material Information sheet lists the components of the eye involved in the function of quantization.

		SUBSYSTEM FUNCTION		MAN																MACHINE												
				INPUT								DIST. AND CONTROL				OUTPUT				INPUT						DIST. AND CONTROL				OUTPUT		
				SENSORY																SENSORS												
				VISUAL	AUDITORY	GUSTATORY	OLFACTORY	TACTILE	RESPIRATORY	UPPER G.I. TRACT	RADIATION	CARDIOVASCULAR	ENDOCRINE	NERVOUS	SMALL INTESTINE	MUSCULO SKELETAL	SKIN	EXCRETORY	REPRODUCTIVE	RADIATION	MAGNETIC	ELECTROSTATIC	FORCE	CHEMICAL	POWER	POWER CIRCUITS	CONTROL CIRCUITS	INFORMATION HANDLING	HEAD AND WASTE DISSIPATION	ACTUATORS	DISPLAYS	RADIATION
			⑦⑧	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
INPUT	DATA	DETECT	79																													
		QUANTIZE	80																													
		QUALIFY	81																													
		TRANSDUCE	82																													
		DISCARD NOISE	83																													
		TRANSMIT INFO. SIGNAL	84																													
	POWER	ACQUIRE	85																													
		QUANTIZE	86																													
		QUALIFY	87																													
		CONVERT	88																													
		DISCARD WASTE	89																													
DISTRIBUTION AND CONTROL	DATA	ACCEPT INFO. SIGNAL	90																													
		ACCEPT INT. CONTROL SIGNAL	91																													
		CONVERT INFO. SIGNAL	92																													
		CORR. CONV. SIG. TO STORE	93																													
		CONV. STORED SIG. TO DEC.	94																													
		TRANSMIT DEC. SIGNAL	95																													
	POWER	ACQUIRE EXT. POWER	96																													
		ACCEPT INT. POWER	97																													
		CONVERT POWER TO STORE	98																													
		CORRELATE STORED POWER	99																													
		CONV.STORED POWER TO INPUT	100																													
		DISCARD WASTE	101																													
OUTPUT	DATA	ACCEPT DEC. SIGNAL	102																													
		CONVERT TO ACTION	103																													
		CORR. WITH STORE	104																													
		TRANSMIT ACTION SIG.	105																													
	POWER	RETRIEVE STORED POWER	106																													
		CONV. TO ACTION	107																													
		CORR. WITH STORE	108																													
		TRANSMIT ACTION	109																													
		SUBSYSTEM CONFIGURATION	110																													
		PARTS	111																													
		SUPPORT STRUCTURE	112																													
		CONTAINER	113																													
		INTERNAL DYNAMICS	114																													
		EXTERNAL DYNAMICS	115																													
		SUBSYSTEM MATERIALS	116																													
		ACCELERATABLE MASSES	117																													
		CONSTRAINED MASSES	118																													
		CHEMICAL CELLS	119																													
		RADIATION SOURCES	120																													
		PERMANENT MAGNENTS	121																													
		ELECTRETS	122																													
		CONDUCTING LOOPS	123																													
		CONDUCTING SURFACES	124																													
		NON-CONDUCTORS	125																													
		SUBSYSTEM TASKS	126																													
			127																													
			128																													
			129																													
			130																													
			131																													
			132																													
			133																													
			134																													
			135																													
			136																													

FUNCTION INFORMATION

FILE NO: 4-80-01

ELEMENT: Man, Input, Sensory, Visual

DEFINITION / FUNCTION	OBJECT	PARA-METER	PROPERTY	CHARACT-ERISTIC	CONVERT TO	METHOD	METHOD SUB-DETAIL NO. 1	METHOD SUB-DETAIL NO. 2	MECH-ANISM	OPERATION	OPERATION SUB-DETAIL NO. 1	OPERATION SUB-DETAIL NO. 2	CHANGE WHEN TOLERABLE LIMITS ARE EXCEEDED
ASPECT: Quantize	Energy of resonant structure				kinetic motion of electrons					conversion of energy			

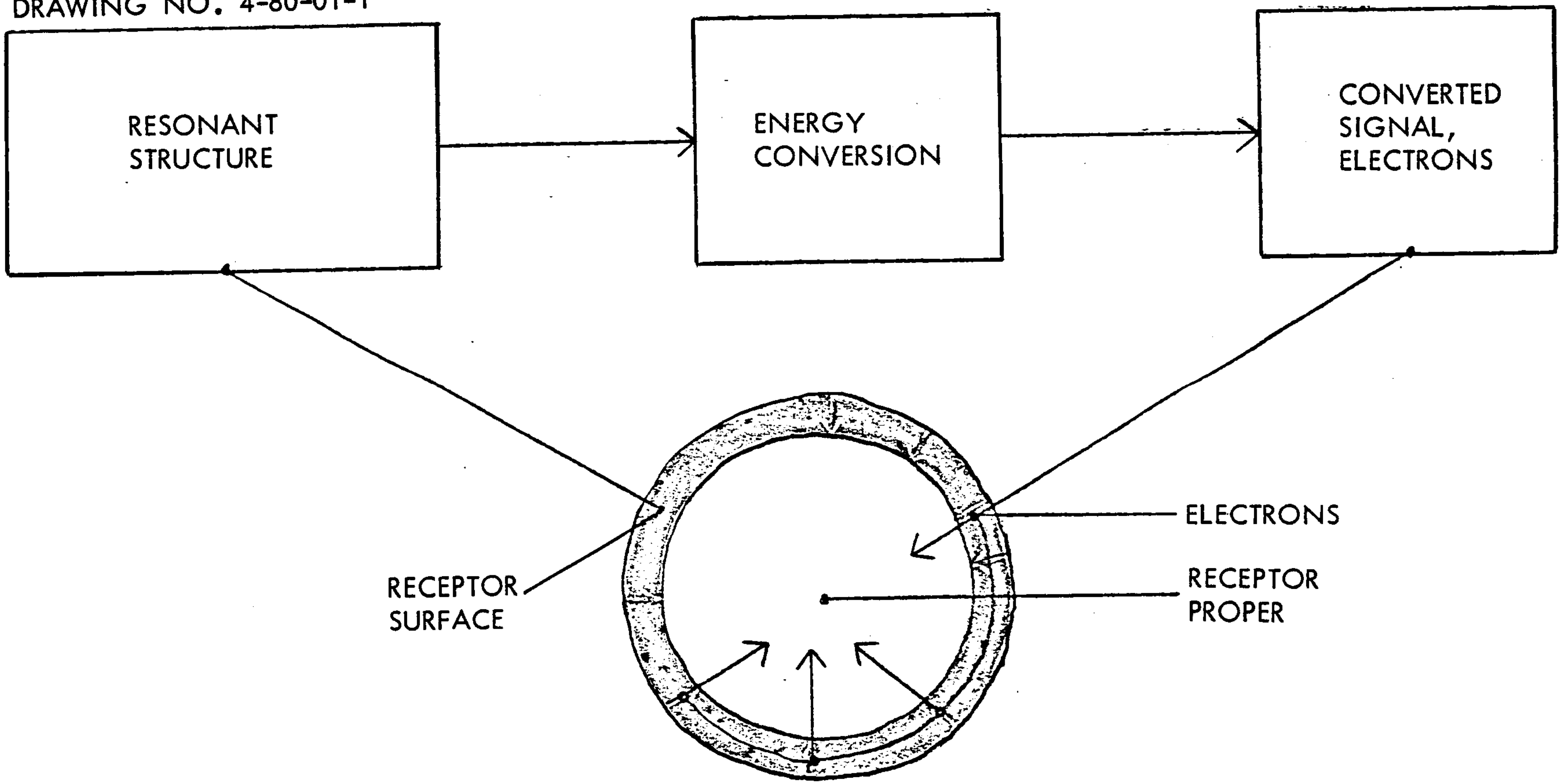
CONFIGURATION INFORMATION

FILE NO.: 4-80-01

ELEMENT: Man, Input, Sensory, Visual

DRAWINGS CONFIGURATION ASPECT:	ARRANGEMENT OF PARTS	CONNECTION OF PARTS	DIMENSIONS	SHAPE	MOTION	DEGREES OF FREEDOM	ENVIRONMENT INTERFACE IN	ENVIRONMENT INTERFACE OUT	CHANGE WHEN TOLERABLE LIMITS ARE EXCEEDED
Parts		quantiza-					air-	receptor	
		tion					cornea	surface-	
		functional						receptor	
		schematic						proper	
		drawing					drawing	drawing	
		no:					no:	no:	
		4-80-01-1					4-80-01-3	4-80-01-4	
		energy							
		dissipa-							
		tion in							
		eye							
		drawing							
		no:							
		4-80-01-2							

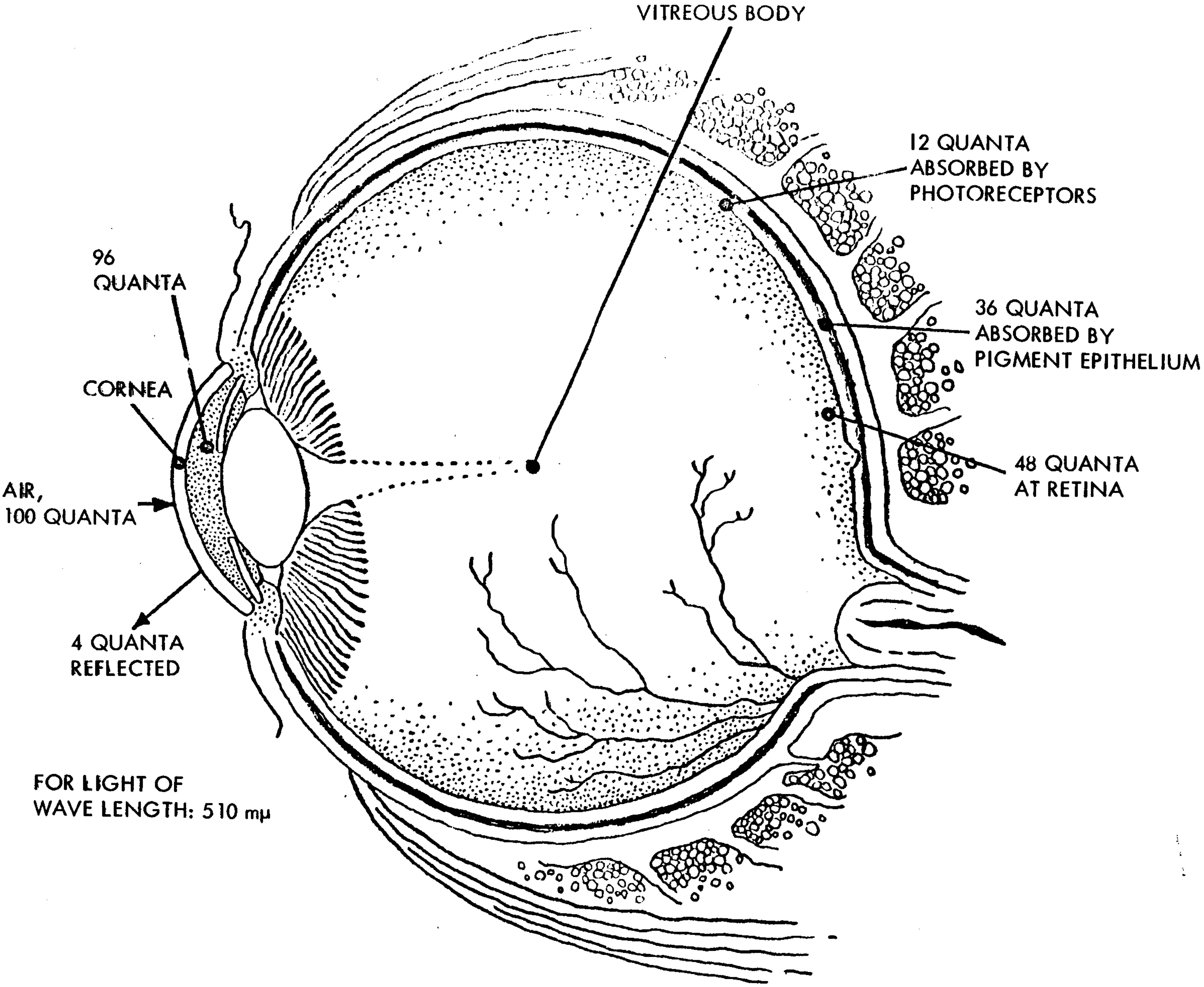
DRAWING NO. 4-80-01-1



QUANTIZATION FUNCTIONAL SCHEMATIC
CROSS-SECTION OF RECEPTOR
CONFIGURATION-CONNECTION OF PARTS

DRAWING NO. 4-80-01-1 TSC 2556

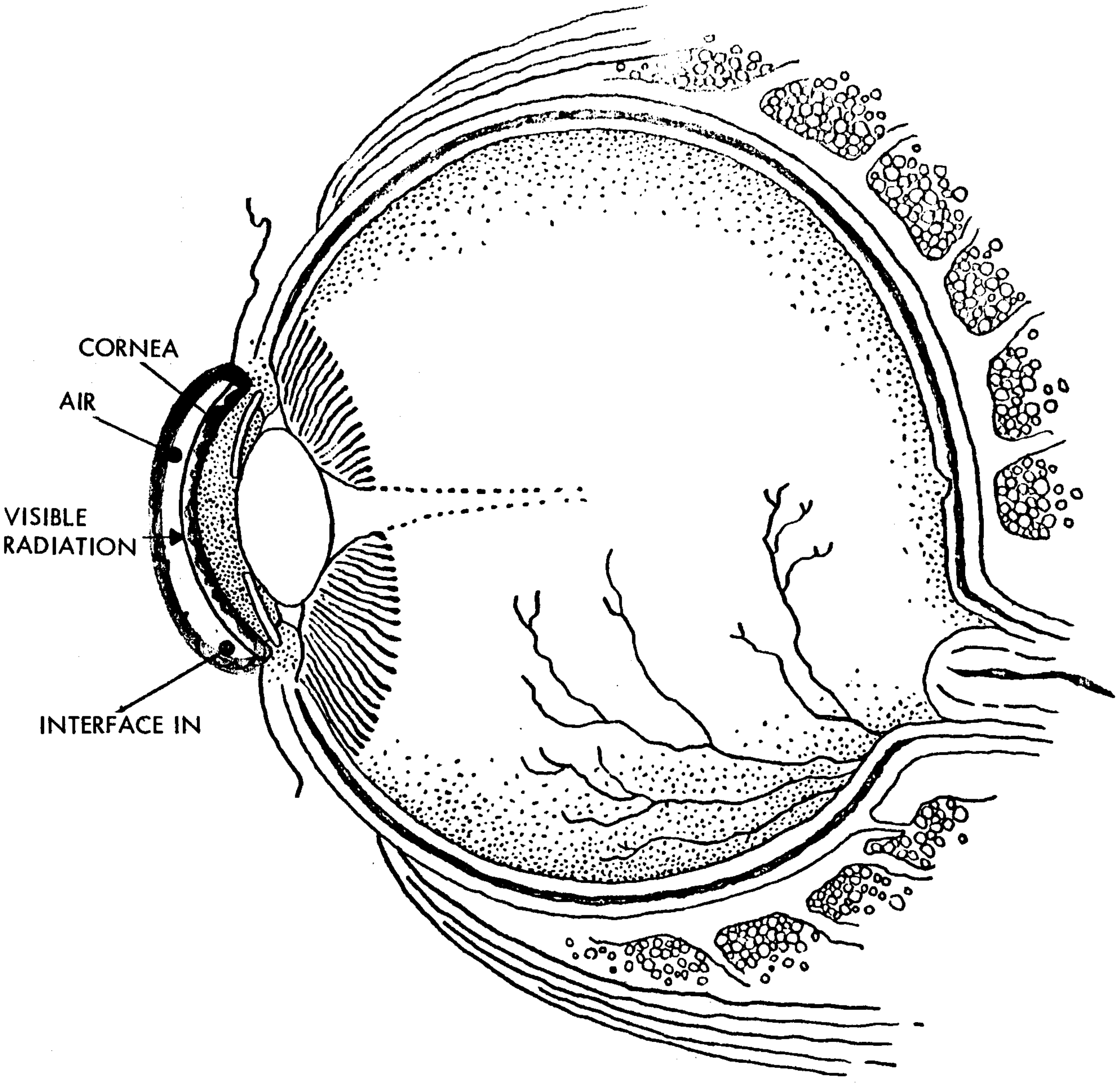
DRAWING NO: 4-80-01-2



(DATA SOURCE: HARTRIDGE, H., RECENT ADVANCES IN THE PHYSIOLOGY OF VISION, 1950, p. 24)

ENERGY DISSIPATION IN EYE
QUANTIZATION FUNCTIONAL ASPECT
CONFIGURATION-CONNECTION OF PARTS
DRAWING NO: 4-80-01-2

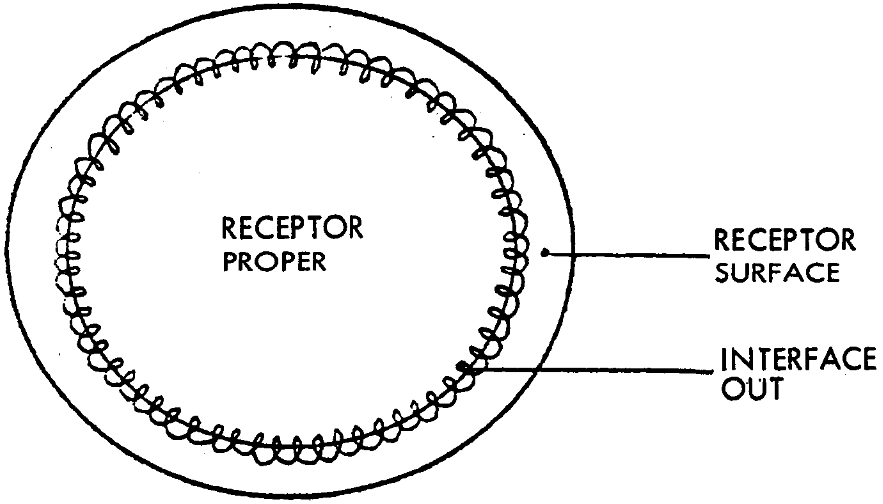
TSC 2218D



CONFIGURATION - INTERFACE IN
TRANSVERSE SECTION OF EYE
QUANTIZATION FUNCTIONAL ASPECT

DRAWING NO: 4-80-01-3

DRAWING NO.: 4-80-01-4



CONFIGURATION - INTERFACE OUT
CROSS SECTION OF RECEPTOR
QUANTIZATION FUNCTION
DRAWING NO: 4-80-01-4

TSC 2528

MATERIAL INFORMATION

FILE NO: 4-80-01

ELEMENT: Man, Input, Sensory, Visual

MATERIALS (next level) / MATERIALS	EXISTENCE	AVAILABILITY	PRODUCIBILITY	RELATIVE COST	REMARKS:
TYPE:					
Cornea					Visible radiation transmitted and reflected by these components
Aqueous humor					
Lens					
Vitreous humor					
Pigment epithelium					Visible radiation absorbed by these components
Rod					
Cone					

TSC 1643

File No: 4-105-01.

This functional aspect discusses the transmission of the action signal from the output portion of the eye to the first neuron encountered in the nervous subsystem. The column labeled Object on the Function Information sheet lists the electric pulses in the optic nerve. These pulses compose the action signal in the output portion of the eye.

The functional aspect of transmission does not alter the energy form of the object and thus the Convert To column lists electric pulses that have entered the lateral geniculate bodies. Under the column headed Operation, the spacial displacement of the electric pulse is mentioned.

The first drawing, No. 4-105-01-1, listed on the Configuration Information Sheet is titled Transmit Action Signal Functional Schematic. Transverse sections of a ganglion cell and a number of lateral geniculate bodies are shown. On the second drawing, No. 4-105-01-2, in this file, the Interface In is shown. Bordering the interface are the nucleus of the ganglion cell and the axon of the ganglion cell (optic nerve). The other end of the optic nerve forms one of the boundaries of the Interface Out diagrammed on Drawing 4-105-01-3. The other components of the boundary are the lateral geniculate bodies.

On the Material Information sheet, the components of the eye involved in the transmission of the action signal are listed.

		SUBSYSTEM		MAN																MACHINE												
				INPUT								DIST. AND CONTROL				OUTPUT				INPUT						DIST. AND CONTROL				OUTPUT		
				SENSORY																SENSORS												
FUNCTION			(78)	VISUAL	AUDITORY	GUSTATORY	OLFACTORY	TACTILE	RESPIRATORY	UPPER G.I. TRACT	RADIATION	CARDIOVAS-CULAR	ENDOCRINE	NERVOUS	SMALL INTESTINE	MUSCULO SKELETAL	SKIN	EXCRETORY	REPRODUCTIVE	RADIATION	MAGNETIC	ELECTRO-STATIC	FORCE	CHEMICAL	POWER	POWER CIRCUITS	CONTROL CIRCUITS	INFORMATION HANDLING	HEAD AND WASTE DISSIPATION	ACTUATORS	DISPLAYS	RADIATION
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
INPUT	DATA	DETECT	79																													
		QUANTIZE	80																													
		QUALIFY	81																													
		TRANSDUCE	82																													
		DISCARD NOISE	83																													
		TRANSMIT INFO. SIGNAL	84																													
	POWER	ACQUIRE	85																													
		QUANTIZE	86																													
		QUALIFY	87																													
		CONVERT	88																													
		DISCARD WASTE	89																													
DISTRIBUTION AND CONTROL	DATA	ACCEPT INFO. SIGNAL	90																													
		ACCEPT INT. CONTROL SIGNAL	91																													
		CONVERT INFO. SIGNAL	92																													
		CORR. CONV. SIG. TO STORE	93																													
		CONV. STORED SIG. TO DEC.	94																													
		TRANSMIT DEC. SIGNAL	95																													
	POWER	ACQUIRE EXT. POWER	96																													
		ACCEPT INT. POWER	97																													
		CONVERT POWER TO STORE	98																													
		CORRELATE STORED POWER	99																													
		CONV.STORED POWER TO INPUT	100																													
		DISCARD WASTE	101																													
OUTPUT	DATA	ACCEPT DEC. SIGNAL	102																													
		CONVERT TO ACTION	103																													
		CORR. WITH STORE	104																													
		TRANSMIT ACTION SIG.	105	■																												
	POWER	RETRIEVE STORED POWER	106																													
		CONV. TO ACTION	107																													
		CORR. WITH STORE	108																													
		TRANSMIT ACTION	109																													
CONFIGURATION		SUBSYSTEM	110																													
		PARTS	111																													
		SUPPORT STRUCTURE	112																													
		CONTAINER	113																													
		INTERNAL DYNAMICS	114																													
		EXTERNAL DYNAMICS	115																													
MATERIALS		SUBSYSTEM	116																													
		ACCELERATABLE MASSES	117																													
		CONSTRAINED MASSES	118																													
		CHEMICAL CELLS	119																													
		RADIATION SOURCES	120																													
		PERMANENT MAGNENTS	121																													
		ELECTRETS	122																													
		CONDUCTING LOOPS	123																													
		CONDUCTING SURFACES	124																													
		NON-CONDUCTORS	125																													
TASKS		SUBSYSTEM	126																													
			127																													
			128																													
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			134																													
			135																													
			136																													

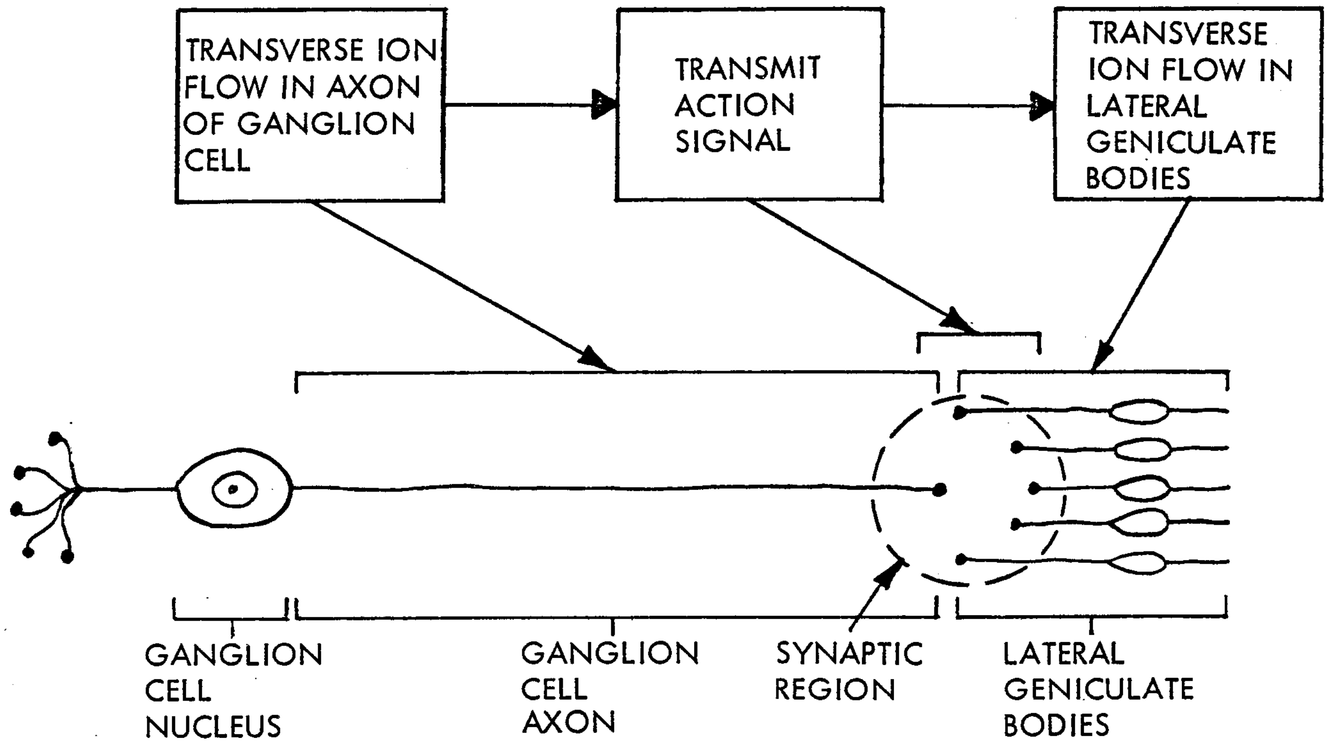
FUNCTION INFORMATION

FILE NO: 4105-01

ELEMENT: Man, Input, Sensory, Visual

DEFINITION / FUNCTION	OBJECT	PARAMETER	PROPERTY	CHARACTERISTIC	CONVERT TO	METHOD	METHOD SUB-DETAIL NO.1	METHOD SUB-DETAIL NO.2	MECHANISM	OPERATION	OPERATION SUB-DETAIL NO.1	OPERATION SUB-DETAIL NO.2	CHANGE WHEN TOLERABLE LIMITS ARE EXCEEDED
ASPECT: Transmit action signal	action signal, electric pulse in optic nerve				electric pulse in lateral geniculate bodies					Spacial displacement of electric pulse			

DRAWING NO: 4-105-01-1



TRANSMIT ACTION SIGNAL FUNCTIONAL SCHEMATIC
TRANSVERSE SECTION OF GANGLION CELL AND LATERAL
GENICULATE BODIES
CONFIGURATION - CONNECTION OF PARTS

DRAWING NO: 4-105-01-1 TSC 2545

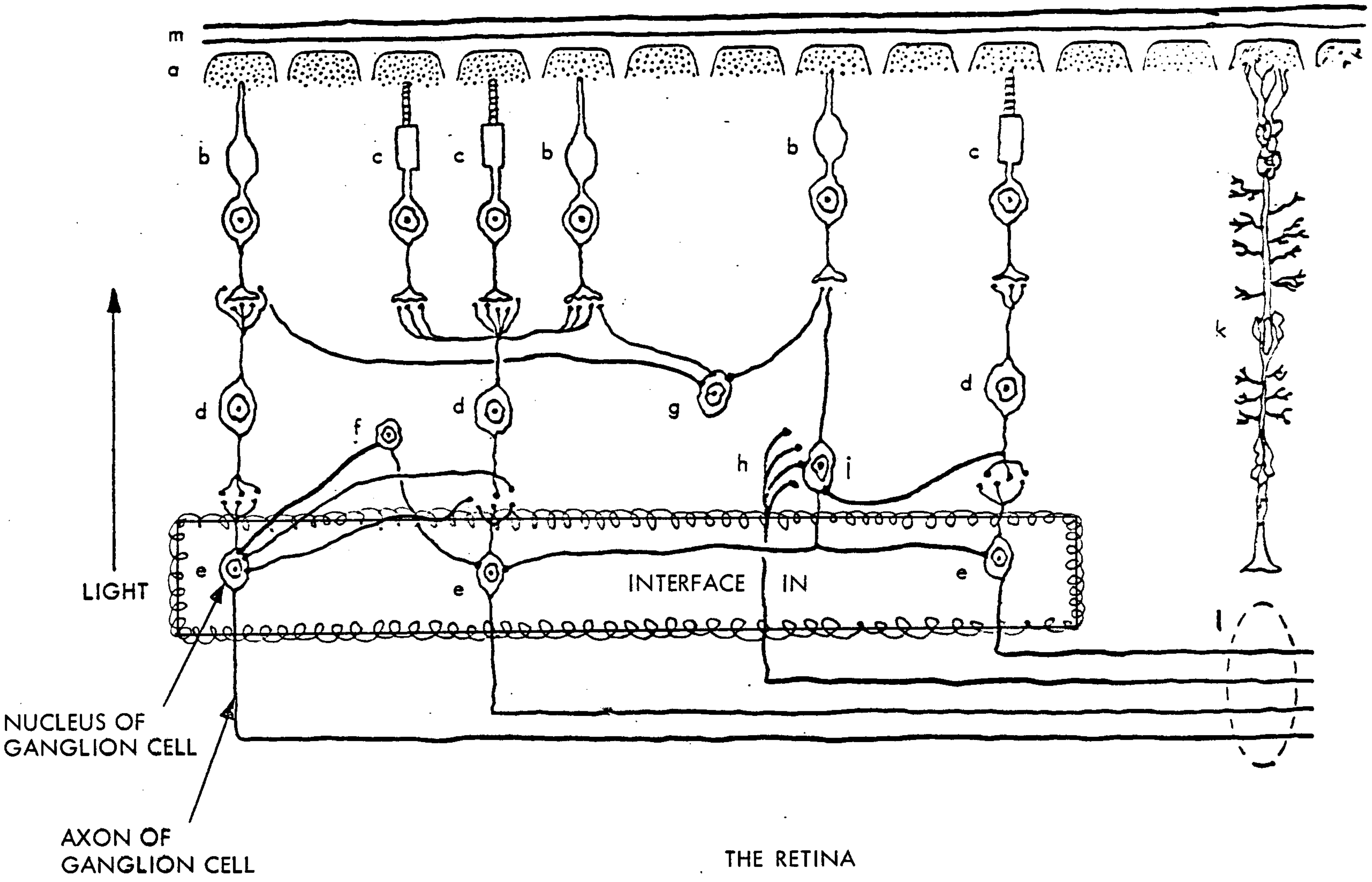
CONFIGURATION INFORMATION

FILE NO.: 4-105-01

ELEMENT: Man, Input, Sensory, Visual

DRAWINGS / CONFIGURATION ASPECT:	ARRANGEMENT OF PARTS	CONNECTION OF PARTS	DIMENSIONS	SHAPE	MOTION	DEGREES OF FREEDOM	ENVIRONMENT INTERFACE IN	ENVIRONMENT INTERFACE OUT	CHANGE WHEN TOLERABLE LIMITS ARE EXCEEDED
Parts		transmit					nucleus	axon of	
		action					of gang-	ganglion	
		signal					lion cell -	cell -	
		functional					axon of	lateral	
		schematic					ganglion	geniculate	
		Drawing					cell	bodies	
		No.					drawing	drawing	
		4-105-01-1					no.	no.	
							4-105-01-2	4-105-01-3	

DRAWING NO. 4-105-01-2



THE RETINA

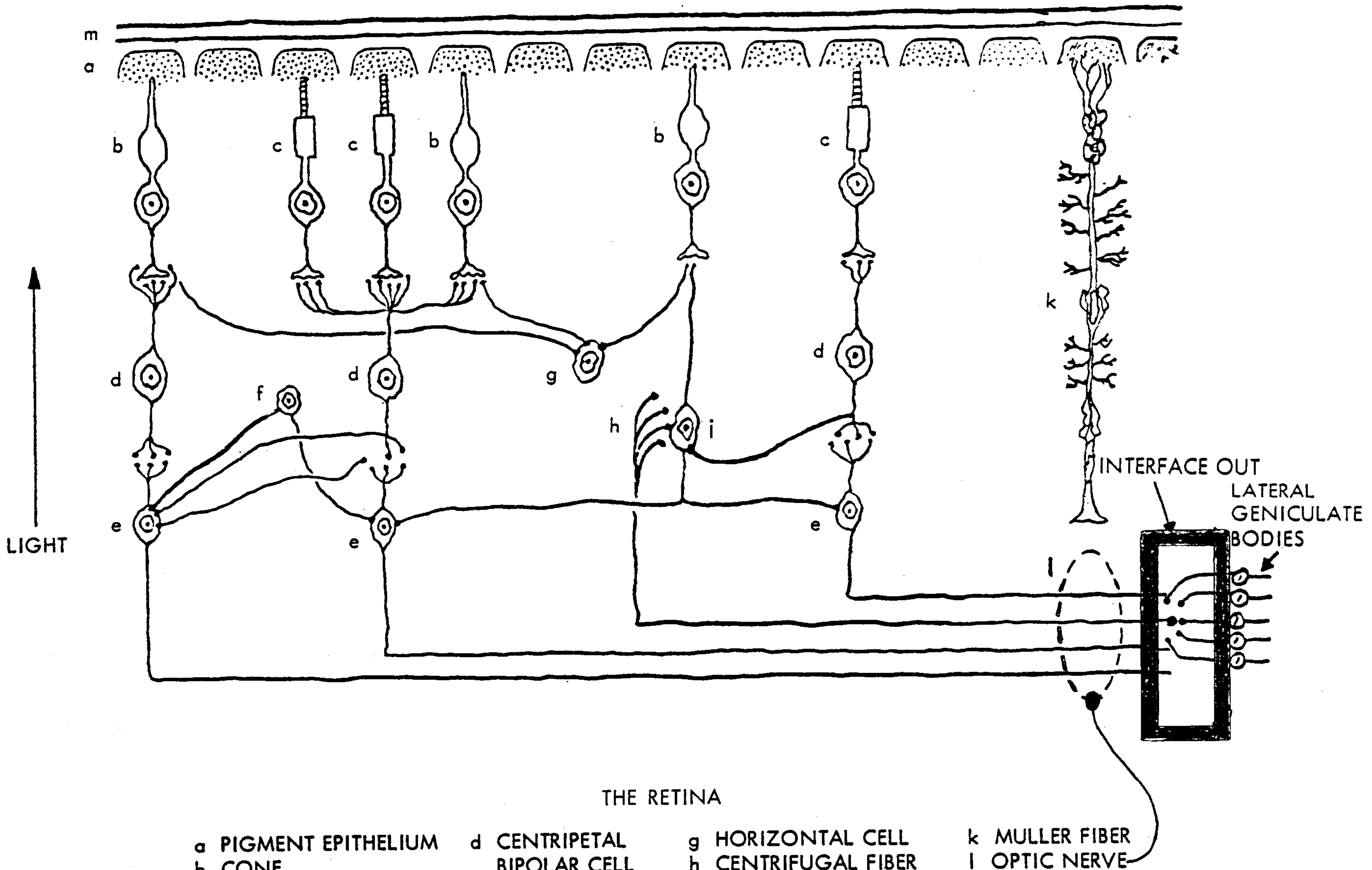
a	PIGMENT EPITHELIUM	d	CENTRIPETAL BIPOLAR CELL	g	HORIZONTAL CELL	k	MULLER FIBER
b	CONE			h	CENTRIFUGAL FIBER	l	OPTIC NERVE
c	ROD	e	GANGLION CELL	i	CENTRIFUGAL BIPOLAR CELL	m	CHORD
		f	AMACRINE CELL				

CONFIGURATION-INTERFACE IN
TRANSMIT ACTION SIGNAL FUNCTIONAL ASPECT

DRAWING NO. 4-105-01-2

TSC 22191

DRAWING NO. 4-105-01-3



THE RETINA

a PIGMENT EPITHELIUM
b CONE
c **ROD**

d CENTRIPETAL BIPOLAR CELL
e GANGLION CELL
f AMACRINE CELL

g HORIZONTAL CELL
h CENTRIFUGAL FIBER
i CENTRIFUGAL BIPOLAR CELL

k MULLER FIBER
l OPTIC NERVE
m CHOROID

CONFIGURATION-INTERFACE OUT
TRANSMIT DECODED SIGNAL FUNCTIONAL ASPECT

DRAWING NO. 4-105-01-3

TSC 2219M

MATERIAL INFORMATION

FILE NO: 4-105-01

ELEMENT: Man, Input, Sensory, Visual

MATERIALS (next level) / MATERIALS	EXISTENCE	AVAILABILITY	PRODUCIBILITY	RELATIVE COST	REMARKS:
TYPE:					
optic nerve					
lateral geniculate bodies					

TSC 1643

File No: 4-111-01, Configuration - Parts

This is the first file under the influencing factor of configuration. File 4-111-01 is for the aspect called parts. On the Configuration Information sheet the column headed Aspect calls out parts. The sheet is a listing of drawings and does not present data.

Two drawings, No. 4-111-01-1 and -2, are called out in the column Arrangement of Parts. These two drawings also show the Connection of Parts. The drawings present an anatomical view of the eye. Next Drawings 4-111-01-3 and -4 give the dimensions of the eyeball and the retina respectively. Drawing 4-111-01-4 indicates that the retina covers an area of 266 mm^2. The retina roughly covers five-sixths of a sphere which is one inch in diameter.

On Drawing 4-111-01-5, the Interface In is shown. The figure indicates that the cornea is the part of the eye that first receives visible radiation. In viewing the Interface Out, Drawing 4-111-01-6, it is seen that the optic nerve and lateral geniculate bodies form the boundary. This is the boundary where the action signal leaves the eye and enters the nervous subsystem.

The Material Information sheet lists the parts of the eye.

		SUBSYSTEM FUNCTION	(78)	MAN																MACHINE												
				INPUT								DIST. AND CONTROL				OUTPUT				INPUT						DIST. AND CONTROL				OUTPUT		
				SENSORY																SENSORS												
				VISUAL	AUDITORY	GUSTATORY	OLFACTORY	TACTILE	RESPIRATORY	UPPER G.I. TRACT	RADIATION	CARDIOVASCULAR	ENDOCRINE	NERVOUS	SMALL INTESTINE	MUSCULO SKELETAL	SKIN	EXCRETORY	REPRODUCTIVE	RADIATION	MAGNETIC	ELECTROSTATIC	FORCE	CHEMICAL	POWER	POWER CIRCUITS	CONTROL CIRCUITS	INFORMATION HANDLING	HEAD AND WASTE DISSIPATION	ACTUATORS	DISPLAYS	RADIATION
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
INPUT	DATA	DETECT	79	☐																												
		QUANTIZE	80	☐																												
		QUALIFY	81	☐																												
		TRANSDUCE	82	☐																												
		DISCARD NOISE	83	☐																												
		TRANSMIT INFO. SIGNAL	84	☐																												
	POWER	ACQUIRE	85																													
		QUANTIZE	86																													
		QUALIFY	87																													
		CONVERT	88																													
		DISCARD WASTE	89																													
DISTRIBUTION AND CONTROL	DATA	ACCEPT INFO. SIGNAL	90	☐																												
		ACCEPT INT. CONTROL SIGNAL	91	☐																												
		CONVERT INFO. SIGNAL	92	☐																												
		CORR. CONV. SIG. TO STORE	93	☐																												
		CONV. STORED SIG. TO DEC.	94	☐																												
		TRANSMIT DEC. SIGNAL	95	☐																												
	POWER	ACQUIRE EXT. POWER	96																													
		ACCEPT INT. POWER	97																													
		CONVERT POWER TO STORE	98																													
		CORRELATE STORED POWER	99																													
		CONV.STORED POWER TO INPUT	100																													
		DISCARD WASTE	101																													
OUTPUT	DATA	ACCEPT DEC. SIGNAL	102	☐																												
		CONVERT TO ACTION	103	☐																												
		CORR. WITH STORE	104	☐																												
		TRANSMIT ACTION SIG.	105	☐																												
	POWER	RETRIEVE STORED POWER	106																													
		CONV. TO ACTION	107																													
		CORR. WITH STORE	108																													
		TRANSMIT ACTION	109																													
		SUBSYSTEM CONFIGURATION	110																													
		PARTS	111	■																												
		SUPPORT STRUCTURE	112																													
		CONTAINER	113																													
		INTERNAL DYNAMICS	114																													
		EXTERNAL DYNAMICS	115																													
		SUBSYSTEM MATERIALS	116																													
		ACCELERATABLE MASSES	117																													
		CONSTRAINED MASSES	118																													
		CHEMICAL CELLS	119																													
		RADATION SOURCES	120																													
		PERMANENT MAGNENTS	121																													
		ELECTRETS	122																													
		CONDUCTING LOOPS	123																													
		CONDUCTING SURFACES	124																													
		NON-CONDUCTORS	125																													
		SUBSYSTEM TASKS	126																													
			127																													
			128																													
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			131																													
			132																													
			133																													
			134																													
			135																													
			136																													

CONFIGURATION INFORMATION

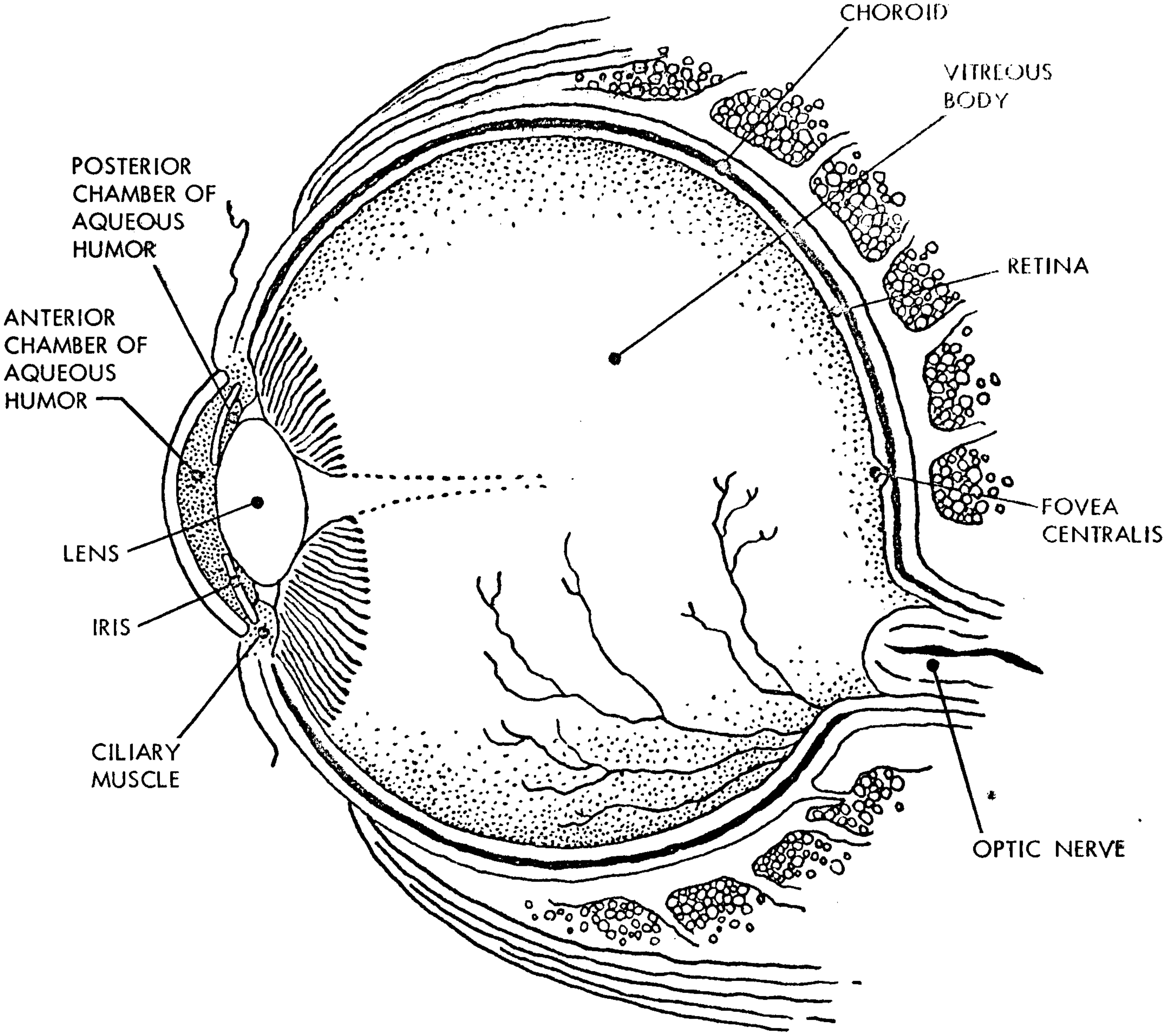
FILE NO.: 4-111-01

ELEMENT: Man, Input, Sensory, Visual

DRAWINGS / CONFIGURATION ASPECT:	ARRANGEMENT OF PARTS	CONNECTION OF PARTS	DIMENSIONS	SHAPE	MOTION	DEGREES OF FREEDOM	ENVIRONMENT INTERFACE IN	ENVIRONMENT INTERFACE OUT	CHANGE WHEN TOLERABLE LIMITS ARE EXCEEDED
Parts	Drawing	Drawing	Drawing	Drawing			air-cornea	optic	
	No.	No.	No.	No.			Drawing	nerve -	
	4-111-01-1	4-111-01-1	4-111-01-3	4-111-01-1			No.	lateral	
	4-111-01-2	4-111-01-2	4-111-01-4	4-111-01-4			4-111-01-5	geniculate	
								bodies	
								4-111-01-6	

TSC 1641

DRAWING NO. 4-111-01-1

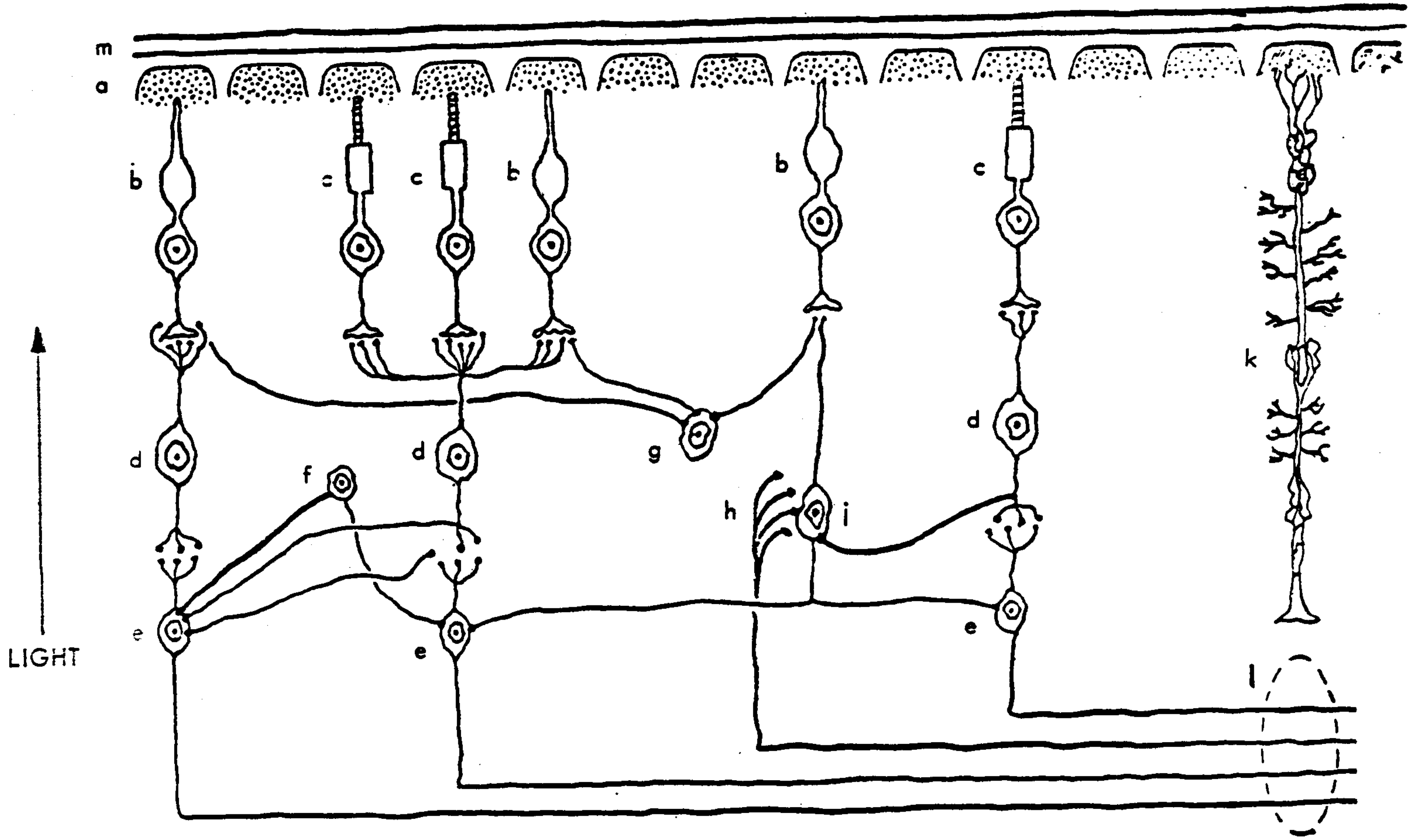


(SOURCE, ATLAS OF HUMAN BODY, FIFTH EDITION, BARNES AND NOBLE, P - 138, 1959)

ARRANGEMENT OF PARTS OF THE EYE
PARTS CONFIGURATIONAL ASPECT
DRAWING NO.4-111-01-1

TSC2218L

DRAWING NO. 4-111-01-2



THE RETINA

a PIGMENT EPITHELIUM
b CONE
c ROD

d CENTRIPETAL BIPOLAR CELL
e GANGLION CELL
f AMACRINE CELL

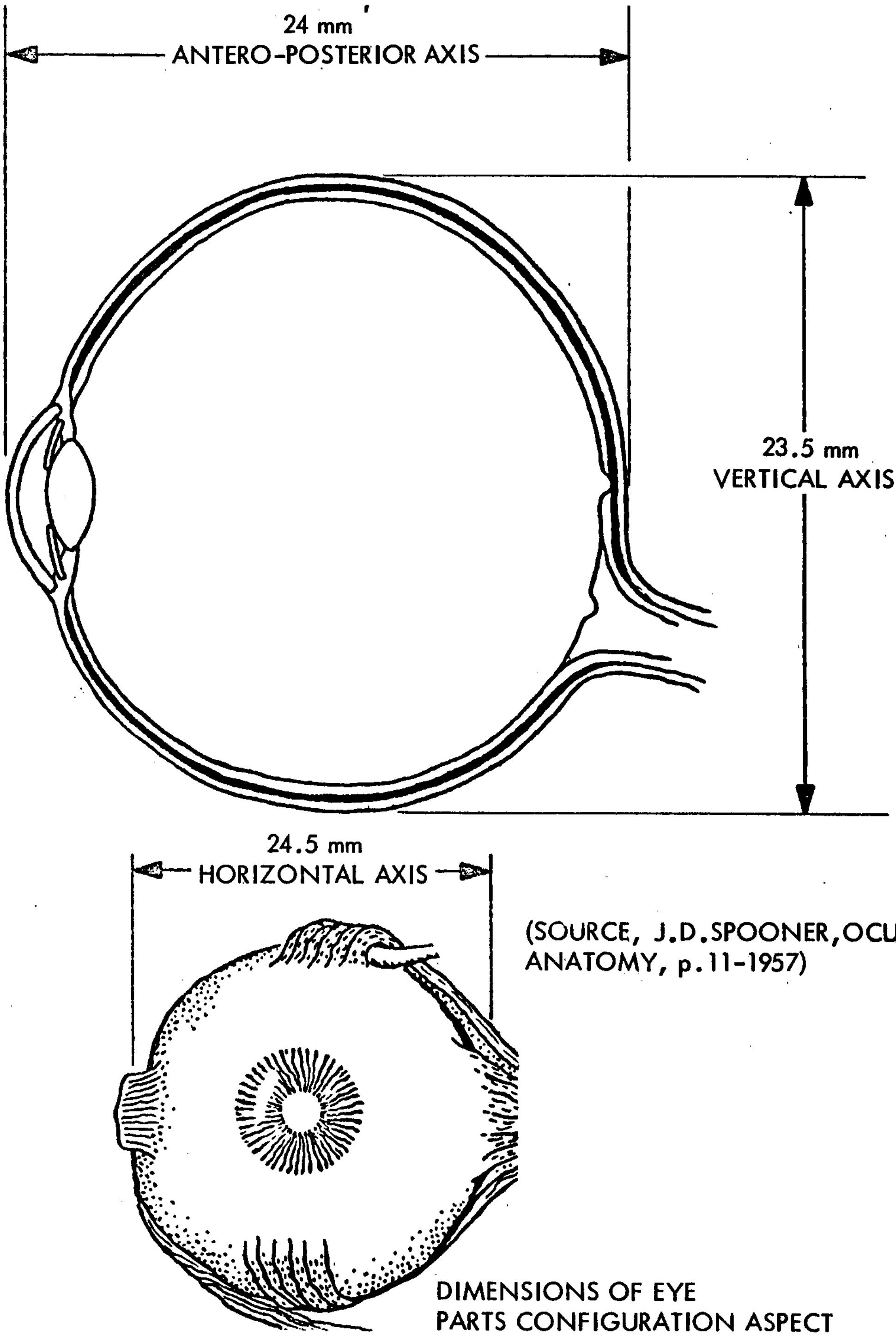
g HORIZONTAL CELL
h CENTRIFUGAL FIBER
i CENTRIFUGAL BIPOLAR CELL

k MULLER FIBER
l OPTIC NERVE
m CHOROID

ARRANGEMENT OF PARTS OF EYE
PARTS CONFIGURATIONAL ASPECT

DRAWING NO. 4-111-01-2

TSC 2219J

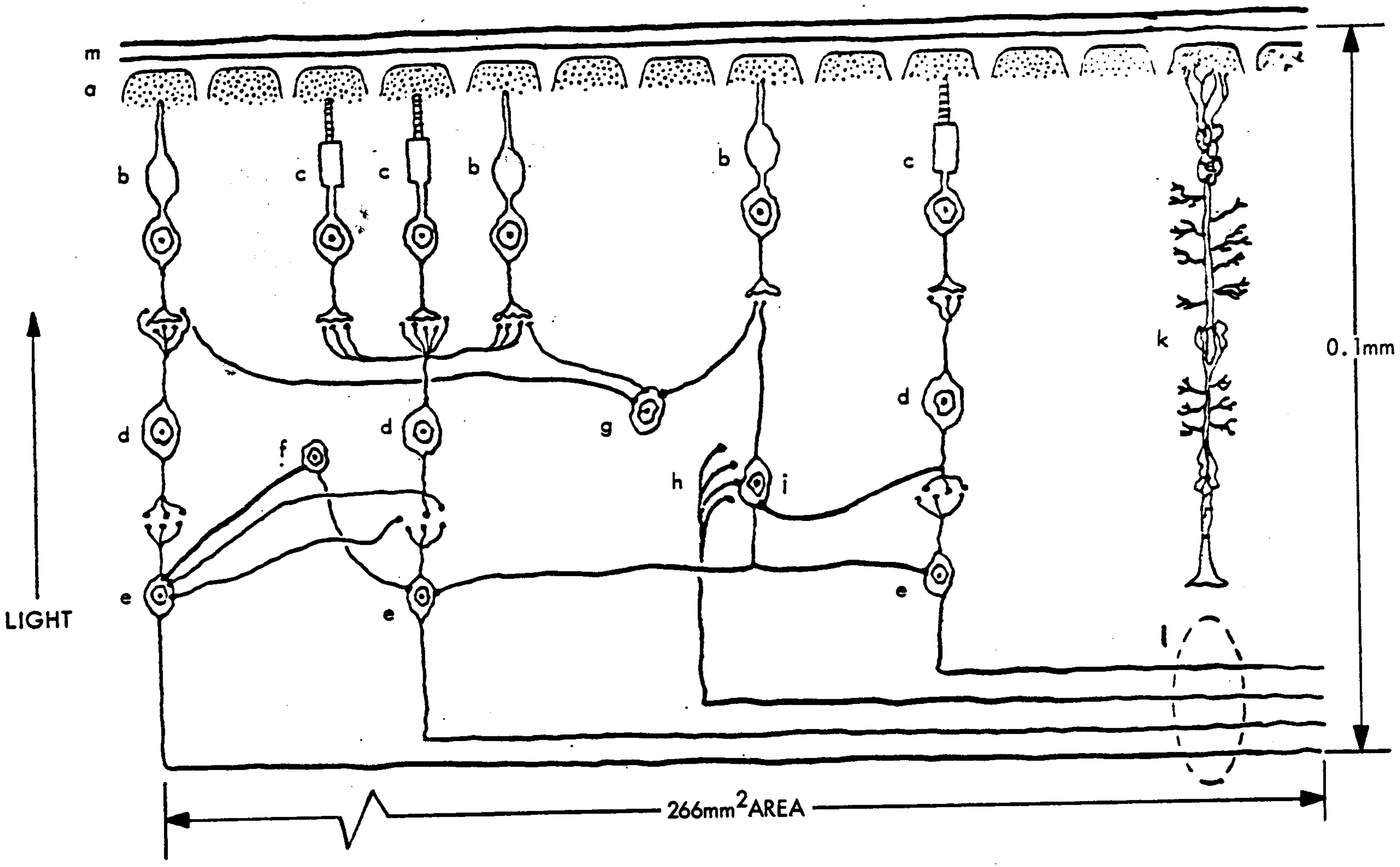


(SOURCE, J.D.SPOONER,OCULAR ANATOMY, p.11-1957)

DIMENSIONS OF EYE
PARTS CONFIGURATION ASPECT
DRAWING NO: 4-111-01-3

TSC 2382A

DRAWING NO. 4-111-01-4



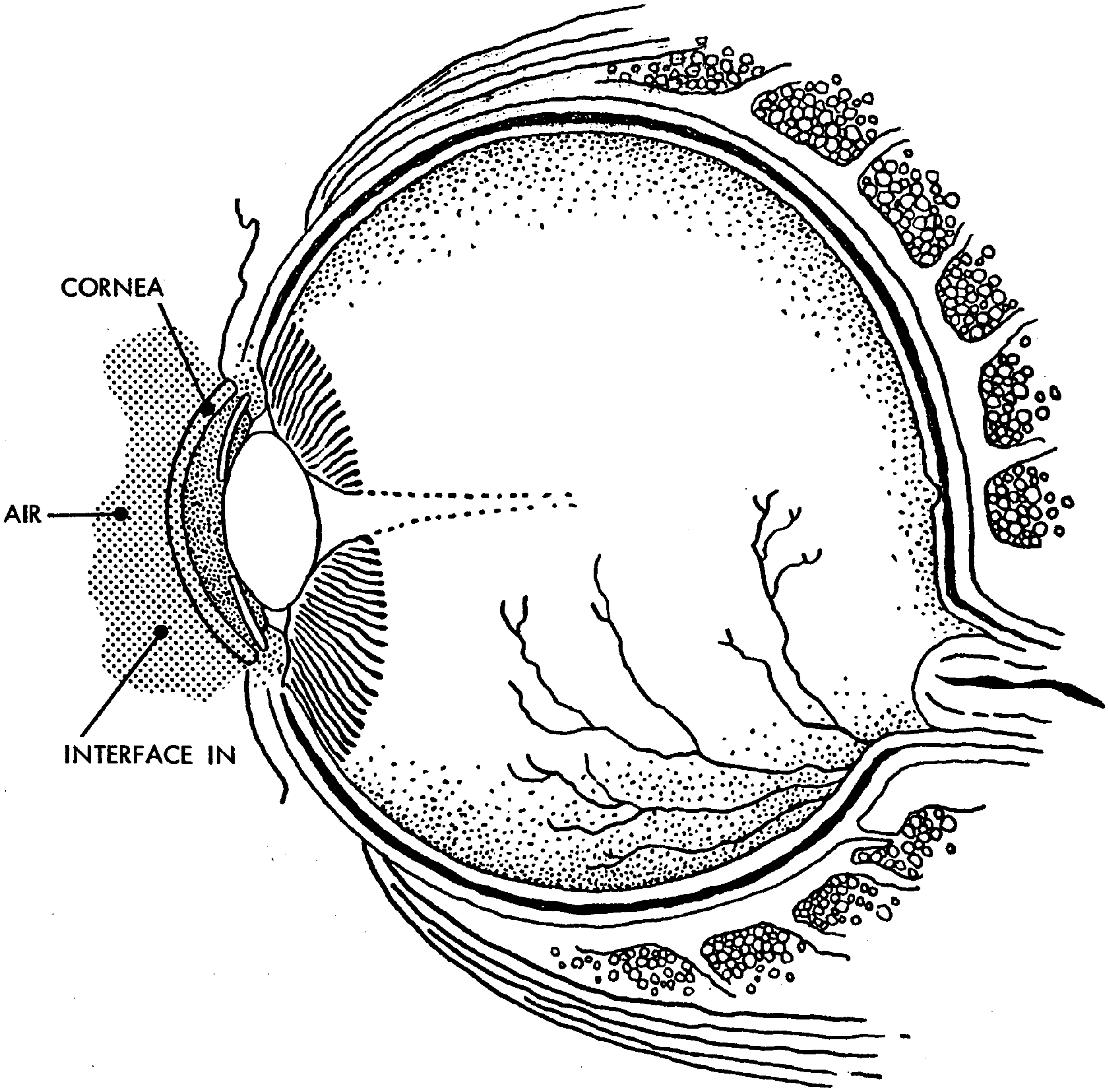
THE RETINA

a PIGMENT EPITHELIUM
b CONE
c ROD
d CENTRIPETAL BIPOLAR CELL
e GANGLION CELL
f AMACRINE CELL
g HORIZONTAL CELL
h CENTRIFUGAL FIBER
i CENTRIFUGAL BIPOLAR CELL
k MULLER FIBER
l OPTIC NERVE
m CHOROID

DIMENSIONS OF EYE
PARTS CONFIGURATIONAL ASPECT

DRAWING NO. 4-111-01-4

DRAWING NO.4-111-01-5

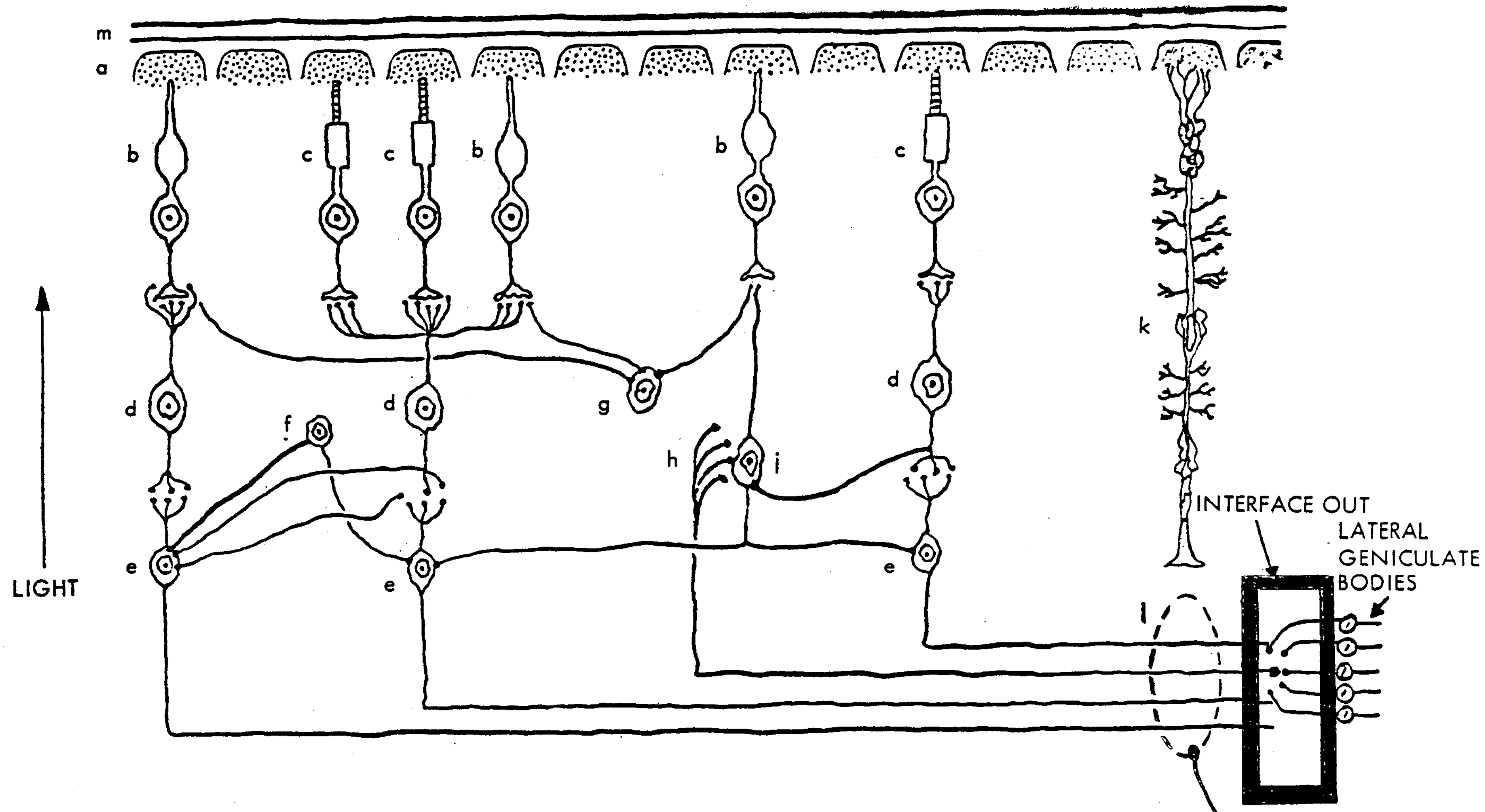


(SOURCE, ATLAS OF HUMAN ANATOMY, FIFTH EDITION, BARNES AND NOBLE,P.138-1959)

INTERFACE IN
PARTS CONFIGURATIONAL ASPECT
DRAWING NO.4-111-01-5

TSC2218K

DRAWING NO. 4-111-01-6



THE RETINA

a PIGMENT EPITHELIUM
b CONE
c **ROD**
d CENTRIPETAL BIPOLAR CELL
e GANGLION CELL
f AMACRINE CELL
g HORIZONTAL CELL
h CENTRIFUGAL FIBER
i CENTRIFUGAL BIPOLAR CELL
k MULLER FIBER
l OPTIC NERVE
m CHOROID

INTERFACE OUT
PARTS CONFIGURATIONAL ASPECT

DRAWING NO. 4-111-01-6

TSC 2219N

MATERIAL INFORMATION

FILE NO: 4-111-01

ELEMENT: Man, Input, Sensory, Visual

MATERIALS (next level) / MATERIALS	EXISTENCE	AVAILABILITY	PRODUCIBILITY	RELATIVE COST	REMARKS:
TYPE:					
cornea					
aqueous humor					
iris					
lens					
ciliary muscle					
vitreous body					
choroid					
retina					
optic nerve					
sclera					
sphincter muscle					
dilator muscle					

File No.: 4-112-01, Configuration - Support Structure

This file contains drawings of the support structure of the eye. On the Configuration Information sheet, two drawings are called out. The first, Drawing 4-112-01-1, is an anatomical illustration that shows the six muscles that move the eyeball as well as the levator muscle that controls the eyelid. The second drawing, No. 4-112-01-2, indicates the direction in which the muscles can rotate the eyeball.

The seven muscles of the support structure are listed on Material Information sheet.

		SUBSYSTEM FUNCTION	(78)	MAN																MACHINE												
				INPUT								DIST. AND CONTROL				OUTPUT				INPUT						DIST. AND CONTROL				OUTPUT		
				SENSORY																SENSORS												
				VISUAL	AUDITORY	GUSTATORY	OLFACTORY	TACTILE	RESPIRATORY	UPPER G.I. TRACT	RADIATION	CARDIOVASCULAR	ENDOCRINE	NERVOUS	SMALL INTESTINE	MUSCULO SKELETAL	SKIN	EXCRETORY	REPRODUCTIVE	RADIATION	MAGNETIC	ELECTROSTATIC	FORCE	CHEMICAL	POWER	POWER CIRCUITS	CONTROL CIRCUITS	INFORMATION HANDLING	HEAD AND WASTE DISSIPATION	ACTUATORS	DISPLAYS	RADIATION
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
INPUT	DATA	DETECT	79																													
		QUANTIZE	80																													
		QUALIFY	81																													
		TRANSDUCE	82																													
		DISCARD NOISE	83																													
		TRANSMIT INFO. SIGNAL	84																													
	POWER	ACQUIRE	85																													
		QUANTIZE	86																													
		QUALIFY	87																													
		CONVERT	88																													
		DISCARD WASTE	89																													
DISTRIBUTION AND CONTROL	DATA	ACCEPT INFO. SIGNAL	90																													
		ACCEPT INT. CONTROL SIGNAL	91																													
		CONVERT INFO. SIGNAL	92																													
		CORR. CONV. SIG. TO STORE	93																													
		CONV. STORED SIG. TO DEC.	94																													
		TRANSMIT DEC. SIGNAL	95																													
	POWER	ACQUIRE EXT. POWER	96																													
		ACCEPT INT. POWER	97																													
		CONVERT POWER TO STORE	98																													
		CORRELATE STORED POWER	99																													
		CONV.STORED POWER TO INPUT	100																													
		DISCARD WASTE	101																													
OUTPUT	DATA	ACCEPT DEC. SIGNAL	102																													
		CONVERT TO ACTION	103																													
		CORR. WITH STORE	104																													
		TRANSMIT ACTION SIG.	105																													
	POWER	RETRIEVE STORED POWER	106																													
		CONV. TO ACTION	107																													
		CORR. WITH STORE	108																													
		TRANSMIT ACTION	109																													
		SUBSYSTEM CONFIGURATION	110																													
		PARTS	111																													
		SUPPORT STRUCTURE	112	■																												
		CONTAINER	113																													
		INTERNAL DYNAMICS	114																													
		EXTERNAL DYNAMICS	115																													
		SUBSYSTEM MATERIALS	116																													
		ACCELERATABLE MASSES	117																													
		CONSTRAINED MASSES	118																													
		CHEMICAL CELLS	119																													
		RADATION SOURCES	120																													
		PERMANENT MAGNENTS	121																													
		ELECTRETS	122																													
		CONDUCTING LOOPS	123																													
		CONDUCTING SURFACES	124																													
		NON-CONDUCTORS	125																													
		SUBSYSTEM TASKS	126																													
			127																													
			128																													
			129																													
			130																													
			131																													
			132																													
			133																													
			134																													
			135																													
			136																													

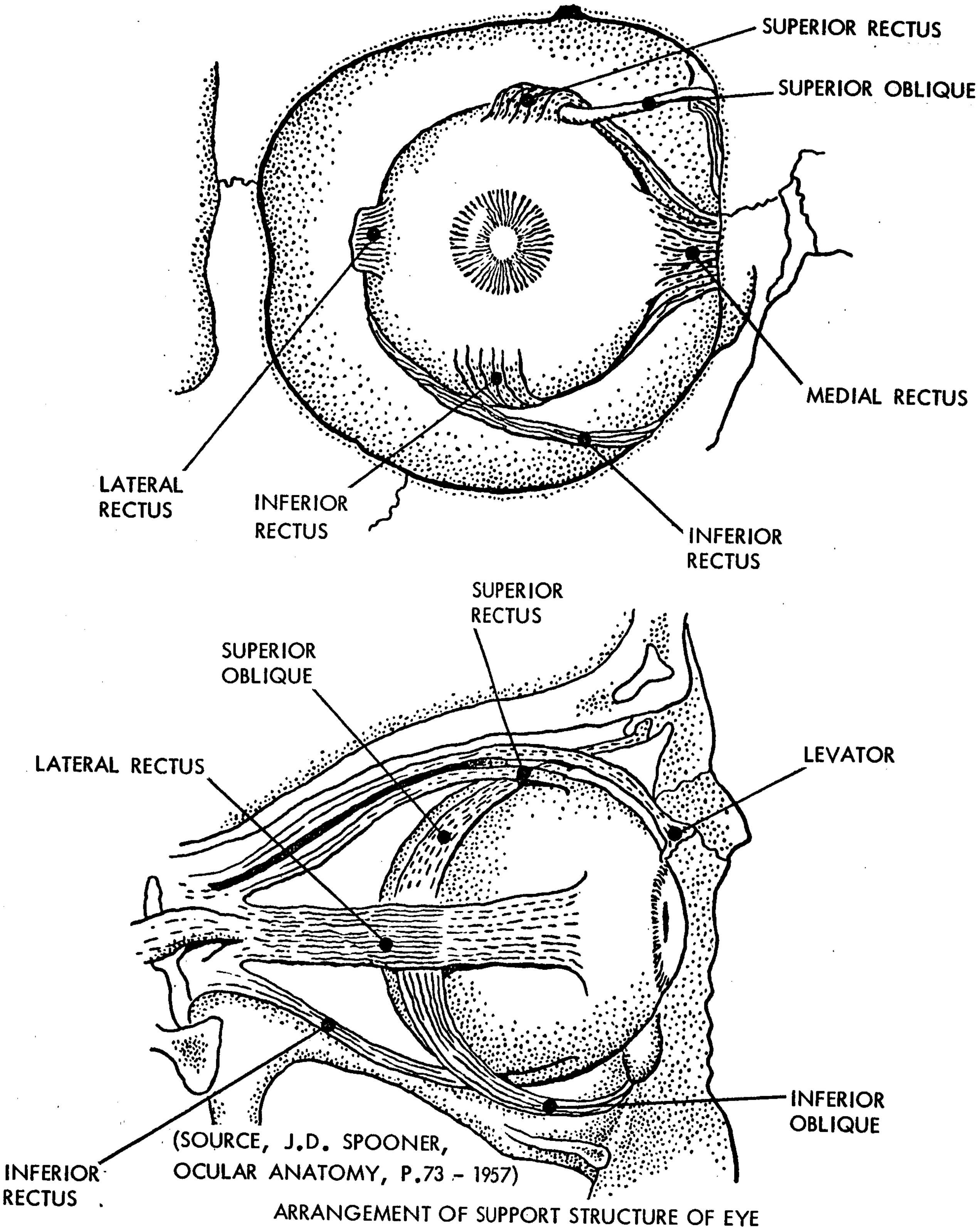
CONFIGURATION INFORMATION

FILE NO.: 4-112-01

ELEMENT: Man, Input, Sensory, Visual

DRAWINGS CONFIGURATION ASPECT:	ARRANGEMENT OF PARTS	CONNECTION OF PARTS	DIMENSIONS	SHAPE	MOTION	DEGREES OF FREEDOM	ENVIRONMENT INTERFACE IN	ENVIRONMENT INTERFACE OUT	CHANGE WHEN TOLERABLE LIMITS ARE EXCEEDED
support	Drawing	Drawing		Drawing	Drawing	Drawing			
structure	No:	No:		No:	No:	No:			
	4-112-01-1	4-112-01-1		4-112-01-1	4-112-01-2	4-112-01-2			

DRAWING NO. 4-112-01-1

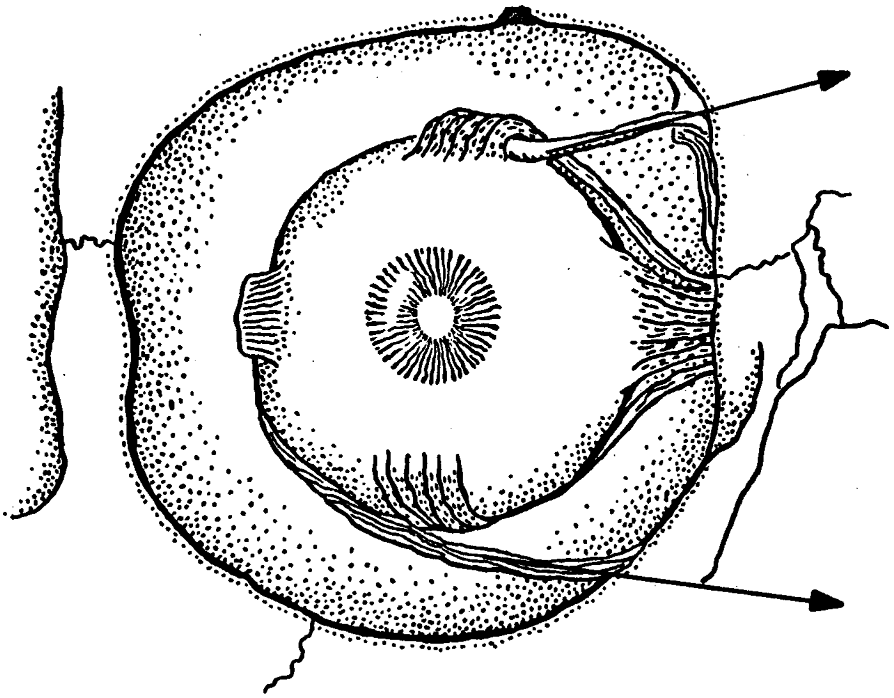


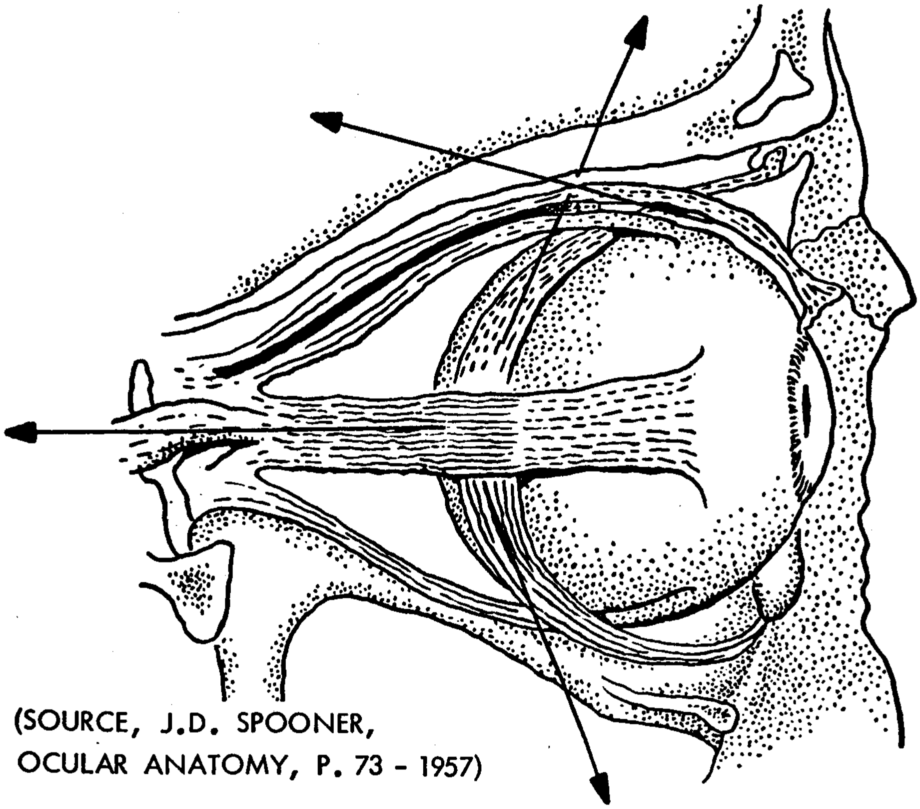
(SOURCE, J.D. SPOONER, OCULAR ANATOMY, P.73 - 1957)

ARRANGEMENT OF SUPPORT STRUCTURE OF EYE
SUPPORT STRUCTURE CONFUGURATIONAL ASPECT
DRAWING NO.: 4-112-01-1

TSC 2220C

DRAWING NO. 4-112-01-2





(SOURCE, J.D. SPOONER, OCULAR ANATOMY, P. 73 - 1957)

MOTION OF SUPPORT STRUCTURE OF EYE
SUPPORT STRUCTURE CONFIGURATIONAL ASPECT
DRAWING NO. 4-112-01-2

TSC 2220B

MATERIAL INFORMATION

FILE NO: 4-112-01

ELEMENT: Man, Input, Sensory, Visual

MATERIALS (next level) / MATERIALS	EXISTENCE	AVAILABILITY	PRODUCIBILITY	RELATIVE COST	REMARKS:
TYPE:					
superior rectus					
inferior rectus					
lateral rectus					
medial rectus.					
superior oblique					
inferior oblique					
levator muscle					

TSC 1643

File No: 4-116-01, Material

The Material Information sheet contains a list of the major components of the eye. No data is entered in the columns labeled Existence, Availability, Producibility, and Relative Cost, since all of the components are known to occur in every human eye. These columns are needed when designing a component.

				MAN																MACHINE												
				INPUT								DIST. AND CONTROL				OUTPUT				INPUT						DIST. AND CONTROL				OUTPUT		
		SUBSYSTEM		SENSORY																SENSORS												
		FUNCTION	78	VISUAL	AUDITORY	GUSTATORY	OLFACTORY	TACTILE	RESPIRATORY	UPPER G.I. TRACT	RADIATION	CARDIOVAS-CULAR	ENDOCRINE	NERVOUS	SMALL INTESTINE	MUSCULO SKELETAL	SKIN	EXCRETORY	REPRODUCTIVE	RADIATION	MAGNETIC	ELECTRO-STATIC	FORCE	CHEMICAL	POWER	POWER CIRCUITS	CONTROL CIRCUITS	INFORMATION HANDLING	HEAD AND WASTE DISSIPATION	ACTUATORS	DISPLAYS	RADIATION
				01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
INPUT	DATA	DETECT	79																													
		QUANTIZE	80																													
		QUALIFY	81																													
		TRANSDUCE	82																													
		DISCARD NOISE	83																													
		TRANSMIT INFO. SIGNAL	84																													
	POWER	ACQUIRE	85																													
		QUANTIZE	86																													
		QUALIFY	87																													
		CONVERT	88																													
		DISCARD WASTE	89																													
DISTRIBUTION AND CONTROL	DATA	ACCEPT INFO. SIGNAL	90																													
		ACCEPT INT. CONTROL SIGNAL	91																													
		CONVERT INFO. SIGNAL	92																													
		CORR. CONV. SIG. TO STORE	93																													
		CONV. STORED SIG. TO DEC.	94																													
		TRANSMIT DEC. SIGNAL	95																													
	POWER	ACQUIRE EXT. POWER	96																													
		ACCEPT INT. POWER	97																													
		CONVERT POWER TO STORE	98																													
		CORRELATE STORED POWER	99																													
		CONV.STORED POWER TO INPUT	100																													
		DISCARD WASTE	101																													
OUTPUT	DATA	ACCEPT DEC. SIGNAL	102																													
		CONVERT TO ACTION	103																													
		CORR. WITH STORE	104																													
		TRANSMIT ACTION SIG.	105																													
	POWER	RETRIEVE STORED POWER	106																													
		CONV. TO ACTION	107																													
		CORR. WITH STORE	108																													
		TRANSMIT ACTION	109																													
		SUBSYSTEM CONFIGURATION	110																													
		PARTS	111																													
		SUPPORT STRUCTURE	112																													
		CONTAINER	113																													
		INTERNAL DYNAMICS	114																													
		EXTERNAL DYNAMICS	115																													
		SUBSYSTEM MATERIALS	116																													
		ACCELERATABLE MASSES	117																													
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		CHEMICAL CELLS	119																													
		RADATION SOURCES	120																													
		PERMANENT MAGNENTS	121																													
		ELECTRETS	122																													
		CONDUCTING LOOPS	123																													
		CONDUCTING SURFACES	124																													
		NON-CONDUCTORS	125																													
		SUBSYSTEM TASKS	126																													
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			129																													
			130																													
			131																													
			132																													
			133																													
			134																													
			135																													
			136																													

MATERIAL INFORMATION

FILE NO: 4-116-01

ELEMENT: Man, Input, Sensory, Visual

MATERIALS (next level) / MATERIALS	EXISTENCE	AVAILABILITY	PRODUCIBILITY	RELATIVE COST	REMARKS:
TYPE:					
cornea					
aqueous humor					
iris					
lens					
vitreous body					
choroid					
pigment epithelium					
rod					
cone					
centripetal cell					
ganglion cell					
horizontal cell					
amacrine cell					
centrifugal cell					
centrifugal fiber					
muller fiber					
optic nerve					
sclera					
superior rectus					
inferior rectus					
lateral rectus					
medial rectus					
superior oblique					
inferor oblique					

(continued on next page)

(continued from previous page)

MATERIAL INFORMATION

FILE NO: 4-116-01

ELEMENT: Man, Input, Sensory, Visual

MATERIALS (next level) / MATERIALS	EXISTENCE	AVAILABILITY	PRODUCIBILITY	RELATIVE COST	REMARKS:
TYPE:					
conjuctiva					
levator muscle					
ciliary muscle					
sphincter muscle					
dilator muscle					

3.0 DISTRIBUTION AND CONTROL SUBSYSTEM

3.1 INTRODUCTION

The distribution and control subsystem that will be examined will be the nervous subsystem. Man's nervous subsystem has been continuously evolving since the first one-celled organism was created, some one billion years ago. Each succeeding generation since has improved the ability of the nervous subsystem to comprehend the energy spectrum of the environment and to direct the manipulation of the energy distribution of the environment.

The nervous subsystem that evolved is a highly perfected mechanism which is capable of operations far exceeding that of the most sophisticated present day computational devices constructed by man. Man's effort in designing computers has produced machines that are indeed much quicker than the nervous system, but their ability to correlate new data, to improve their responses, to operate in new modes, and generally to adapt is severely limited.

Man today is becoming aware of the bionic possibilities that can be achieved by taking advantage of a carefully selective one billion years of life followed by a brief but well directed million years that have produced the very nearly perfect nervous subsystem of man. The nervous subsystem deserves the attention of physicians, physiologists, engineers, and scientists in order to learn the mechanism of operation of this subsystem. There are many possible applications for the information gathered by these workers. Study of the nervous subsystem will yield new insights into machine analogs. Machine analogs may be used to replace injured or disabled portions of this distribution and control subsystem, and they may be used to extend man's nervous subsystem. Supplementary control capacity would be highly useful to individuals, such as astronauts, that must make many complex decisions in a short period of time. If these people had the use of auxiliary distribution and control subsystems, they could direct these units to aid in the manipulation portions of the decision process.

Initially, data would be accepted through man's sensory subsystems such as his tactile, visual, or auditory subsystems. Data that was felt to require manipulation involving critical decisions could be handled within man's nervous subsystem, while more routine information could be directed by the nervous subsystem to proceed to the auxiliary neural processing extender. In this supplementary unit, the data could be examined and a suggested mode of action could be transmitted back to man's nervous subsystem. Thus, a machine analog of the nervous subsystem holds the promise of considerably extending man's data processing abilities.

Present data processing techniques are centered around the utilization of computers that all operate using number systems of differing radix. The necessity of using a number system means that computers must translate real world variables into numbers. Frequently this translation is difficult, expensive, and of an accuracy that is much below that of the computer itself. Answers to real world problems could be found much more directly if the translation to a synthetic numerical quantity could be avoided.

The nervous subsystem does not utilize a numbering system and yet is capable of acting appropriately when presented with a problem. Indeed, this subsystem has many other advantages over presently available data processing devices; for instance, the nervous subsystem has an average life expectancy of about 70 years during which time no externally made repairs are needed, redundancy of information flow is extremely high, consequently reliability is also high, and the accuracy is adequate for life needs. Interestingly, this accuracy is produced by the utilization of many non-precise components. These components, the neurons, are the building blocks of the nervous subsystem.

A thorough study of neurons is the first step in the development of a data processing device that will not need to transform real world problems into numerical form, that will have long life, be highly reliable, have adequate accuracy, and be capable of adaptive behavior. Teledyne has conducted an investigation into the histology and physiology of the neuron. This study was directed toward finding those aspects of neuron physiology that could be used in the development of a non-numeric data processing device.

The physiology of the neuron was presented in a fashion that would enable the reader to grasp the chronologic development of the concepts of neural function and operation. Only experimental work that has been fruitful in leading to our present understanding was discussed. Most of the major breakthroughs in neural investigation were cited and details were given in areas that could help to sow the ideas for a data handling element that would not utilize numbers.[1]

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1. Second quarterly report under this contract, section entitled, "Physiology of the Vertebrate Neuron."

The neuron-like model that Teledyne has developed from its study of the physiology of the nervous subsystem has been given the name non-numeric element. Inequality is the basic property around which this element has been mechanized; therefore, outputs are of the maximum-minimum type. By specific interconnections of two elements, units can be created that are either able to distinguish the greater of two inputs or the lesser. Only one element is needed to produce the complement of an input. Methods for generating a neuron model with a zero threshold or a gain of unity will be developed. A graphical approach to the two variable non-numeric network will be described, and a rigorous synthesis technique will be demonstrated which will allow the mechanization of all "realizable functions."

Next, the development of an active non-numeric element with a memory is presented. A discussion is given of the biological techniques of transforming spacial and temporal sensory information into a form that can be stored in the non-numeric memory element. Significant properties of the biological system are adopted for application in the memory of the non-numeric system. Then the rules for correlation of new and stored data are established.

Mechanization of a correlator begins by describing the transformation of incoming information in a non-numeric system. It is shown that a correlator can be mechanized with three non-numeric elements. As an illustration of the operation of a correlator, an example is worked to yield the resultant correlator outputs, which are graphically analyzed. In deriving the transformation networks that convert sensory data into a four-region information plane, the operational relationships for the two transducers used were first graphically established. The derivation showed that each of the four spacial points of the information plane could be generated by the Max function generator. A plot of the four regions indicates the three dimensional characteristic of the transformation networks..

Following the examination of four-region information planes, there is a section dealing with the transformations for three-region planes. As the discussion in this section points out, reducing the number of information planes increases the complexity of the transformation networks; in fact, to mechanize a three-region information plane requires the use of non-linear, non-numeric components. Each non-linear component is composed of two simple non-numeric elements and one memory element. Two of the three required transformation networks for a three-region plane are non-linear, non-numeric components. The third is yet more complex in that one linear and two non-linear, non-numeric elements are needed to mechanize the network.

This section of the report closes with a discussion of a broad system application of the non-numeric data handling device. Beside the capability of correlating new data with old, the system can create new plausible patterns by combination of two or more old patterns. A censor checks for possible contradiction between input patterns and existing stored memory planes. If there is high correlation between these two, the new pattern modifies the existing memory plane. On the other hand, for low correlation, the inputwill be stored as a completely new pattern. Thus, the non-numeric data handling system learns by experience.

3.2 HISTORICAL DEVELOPMENT OF ADAPTIVE DEVICE CONCEPTS

There have been a number of workers who have studied the histology and physiology of the biological neuron and then utilized this examination to evolve neuron-like elements whose operation is based on selected physiological principles. One of the early researchers in this area was N. Rashevsky. In 1938, he published a paper called Mathematical Biophysics in which he described his investigation into the manner in which nerve nets consisting of formalized neurons and connections might be made to perform psychological functions.

Five years later, W. S. McCulloch and W. Pitts published "A Logical Calculus of the Ideas Immanent in Nervous Activity." McCulloch and Pitts proposed a representation of neural elements and their properties that permitted a strict logical analysis of any complex network. The fundamental thesis of their work is that all psychological phenomena can be analyzed and understood in terms of activity in a network of two-state (all-or-nothing) logical devices. The McCulloch-Pitts neuron model did not include a permanent memory, although elements could be modified by changes in existing circulatory loops by impulses within the network. If this system was turned off, even temporarily, then all memory of previous inputs and outputs was obliterated.

A direct descendant of the McCulloch-Pitts neuron was the perceptron put forth by F. Rosenblatt of Cornell University. The term perceptron was originally intended as a name for a variety of theoretical nerve nets. Perceptron research has been concerned with the investigation of physical structures and neurodynamic principles that underlie natural intelligence. Perceptron models illustrate a number of the processes by which organisms or non-living organized systems are able to gain knowledge of the physical world. These models contain a memory mechanism that permits them to learn responses to stimuli in various types of experiments. The perceptron is first and foremost a brain model.

A perceptron consists of a set of neurons connected together to form a network. Each perceptron includes a sensory input and one or more output units. The logical properties of a perceptron are defined by its topological organization (the connections between neurons), the rules for generating and transmitting signals, and the rules for modification of the network properties as a consequence of activity. Most analyses are not concerned with a single perceptron, but with the properties of a class of perceptrons, whose topological organizations come from some statistical distribution. A perceptron is different from other types of brain models, in that it relies on acquired biases and allows considerable freedom in establishing its connections.

Another statistical adaptive system has been investigated by W. R. Ashby and described in his book, Design of a Brain. In this book, Ashby has demonstrated in a number of experiments how statistical mechanisms can yield adaptive behavior in an organism. Although the book does not specify an actual brain model, it does develop a logical basis to analyze closed systems, including their environment, as well as the responses of the adaptive element and the interactions of groups of these elements.

In his book The Organization of Behavior, written in 1949, D. O. Hebb has attempted to show how an organism can acquire perceptual capabilities through an adaptive process. Hebb's model is relatively detailed in its biological description and suggests a process by which neurons, that are frequently activated together, become linked into functional organizations called cell assemblies and phrase sequences. A stimultion of these functional organizations corresponds to the evocation of an elementary idea.

Research sponsored by Wright Air Development Division and the Office of Naval Research at Stanford Research Institute has resulted in the formulation of a neuron-like element called the neuristor. Work on this project was begun by H. D. Crane and A. Rosengreen in 1960. The neuristor that they developed is a device that exhibits attenuationless signal propagation, as in the electrical discharge along the axon of a nerve fiber. Attenuationless propagation is no violation of energy conservation because, as the signal propagates in a neuron and in a neuristor, energy flows "transversely" into the line.

A neuristor line consists basically of a distributed active element arranged so that, when any portion of line is triggered, some or all of the locally available energy is converted into a form suitable for triggering the neighboring section of line. The line structure employed utilized relays as the active device. Relays were used because they produce propagation delays as do biological neurons.

The three following effects were found during this research.

1. Pulse destruction by rear-end collision with a pulse ahead.

2. Pulse-locking, in which a pulse takes up one of a set of stable positions behind the pulse ahead.
3. Pulse creation, which results from certain line dynamics that causes a section of line that is periodically excited to resonate to the extent of creating pulses locally

Another neuron-like device that is being studied at Stanford University is the memister. In 1963, a paper by B. Widrow and F. W. Smith entitled "Pattern-Recognizing Control Systems" was written. The paper describes how adaptive logic networks constructed of memisters have been used in an automatic control system.

A memister is a resistor with memory that provides a single variable gain element. Each neuron thus employs a number of memisters equal to the number of input lines, plus one for the threshold. The memister consists of a conductive substrate with insulated connecting leads, and a metallic anode, all in an electrolytic plating bath. Conductance of the element is reversibly controlled by electroplating. Control of conductance between two of the terminals is achieved by means of time integration of the current in the third terminal of the memister. Elements have been produced which vary in resistance from 2-50 ohms. This range can be covered in about 15 seconds with several tenths of a milliampere of plating current. Adaption is accomplished by direct current and sensing by alternating current.

Memisters are used in fabricating Adalines (adaptive linear neurons), which are the basic building blocks of the system. A procedure for training Adalines is the minimum change rule. This rule dictates that no change in adaptation will be made if the system output is correct. If the system output is in error, a minimum number of the incorrect Adalines are adapted. The Adalines that will be chosen for adaption are those whose analog responses require the least amount of change to give the proper output. The principles that have been formulated for Adalines have been applied to control systems, speech recognition, and diagnosis of EKG waveforms. Weather forecasts that were quite similar to those generated by the U. S. Weather Bureau have been accomplished by means of Adaline-type trainable networks.

Work at the Radio Corporation of America in New Jersey by G. J. Duscheck, T. G. Hilinski, and F. L. Putrath has been described in a paper entitled "A Flexible Neural Logic Network." This paper was presented at the 1963 Bionics Symposium. The paper describes flexible neural networks that have been built and are able to modify their logic functions by the adjustment of continuously variable controls. These neurons are stimulated by means of variable firing rates as is the biological neuron. These inputs are utilized by the RCA models to yield analog output signals. The analog properties of these models have been found to be advantageous in the development of adaptive logic systems. In networks of these elements, it is possible to quantitatively determine the magnitude of the corrective signal that must be applied to each variable of the system and thus reduce the period of adaptation. RCA has found that networks of simulated neurons are desirable in classifying temporal patterns, because the sequence of simultaneity of events can be measured efficiently.

3.3 TELEDYNE'S NEURAL MODEL

Research at Teledyne has led to the development of a neuron-like element. This model differs markedly from other previously conceived neurological devices. First, an adjustable memory whose storage capabilities do not depend on system power application is utilized. It is thus possible to cause the Teledyne system to be modified by an internal adaptive process and not have the system revert to the non-specific form when power is removed unless so desired by the operator. Networks of Teledyne neuron elements are configured on the basis of formal synthesis techniques evolved to completely describe minimal network interconnections required to perform specific functions. Finally, Teledyne's neural model utilizes variations in average pulse repetition rate as the information format in a manner similar to the biological neuron. It is felt that these techniques can be applied within today's state of art to current decision-type problems. Relatively few neurons of the type to be described are required to comprise networks having useful properties in system design.

The model to be described has three basic parameters that are characteristic of the biological element. These parameters are threshold value, gain factor, and saturation value. Recognition by Teledyne of the non-numeric nature of the biological neural network has led to the formulation of a new approach to data handling, i.e., the solution of problems on the basis of inequalities. Comparisons of any type can be performed without recourse to numbers. In a manner similar to the operation of a chemical balance, two signals in a net can be weighed to establish maximum-minimum relationships without referring to their numerical magnitude. The system of inequalities thus defined permits solutions to be produced of a decision-making type.

By developing the non-numeric property, there are a number of advantages that can be realized. First, machine components need not be designed and fabricated to close operational tolerances, because there is no need to receive, store, manipulate, or transmit specific numerical quantities. Another advantage of the non-numeric approach to neuron models is that systems composed of these elements can more easily interface with external stimuli. For example, in the case of a digital computer, every system input must be transformed by means of an analog to digital converter before meaningful data is able to enter the system. An analog system need not make this type of conversion, but of great concern are the linearity and drifts associated with the components that comprise the system. These restrictions are not required in the operation of the biological neuron nor are they required for the operation of Teledyne's neuron-like element.

The non-numeric data handling system makes a conversion from input stimuli to average pulse repetition rate. The only requirement is that the response to stimuli be monotonic. That is, an increasing amount of stimulus must produce increasing stimulus over the range of the system. No linearity requirements or zero offset requirements exist. Thus input devices can be easily mechanized. Average repeition rates then are directed to trigger non-numeric elements comprising the various networks in the system. Thus, the non-numeric approach yields benefits in its simplicity of design and construction and in its ability to interface with sensory stimuli.

3.4 MATHEMATICAL DESCRIPTION OF THE NON-NUMERIC DATA HANDLING ELEMENT

3.4.1 Inputs

There may be a large number of inputs to a non-numeric data element. The inputs are of two types, stimulatory (s) and inhibitory (i). Stimulatory inputs evoke a response from the element while inhibitory inputs oppose the formation of a response. Both s and i inputs can vary in intensity; therefore, they can contribute differing amounts to the production (or non-production) of a response. Thus weighting factors will be applied to the s and i factors. The multiplier a will be used with s inputs, and b will be used with i inputs.

3.4.2 Outputs

When the combined effect of the inputs (a s - b i) exceeds a threshold value (σ), a response is evoked. The magnitude of the response is:

$$\rho = \left[\sum_{j=1}^{n} a_j s_j - \sum_{j=1}^{n} b_j i_j - \sigma \right] K ,$$

where K is the gain factor of the element. A maximum response can be considered to be equal to ψ, which is the saturation value of the component. In forming an equation for the output, R, it should be realized that R cannot be negative. This can be deduced by recalling a few statements made about the physiology of the neuron.

Recent research has disclosed that a neuron cannot produce both excitatory and inhibitory action. Afferent fibers from endings of muscle spindles are excitatory, while inhibitory action is produced by interneurons. Since we are dealing with an element that yields excitatory responses, we can only produce positive excitations or no response. Thus the output of the element is:

$$R = \max(\rho, 0)$$

The form of this equation is basic in the development of a non-numeric component. In the equation above, R is equal to either ρ or 0 (zero), whichever is greater, and therefore R cannot be negative. To take into account the maximum possible response, the saturation value (ψ) of the element can be introduced into the equation above.

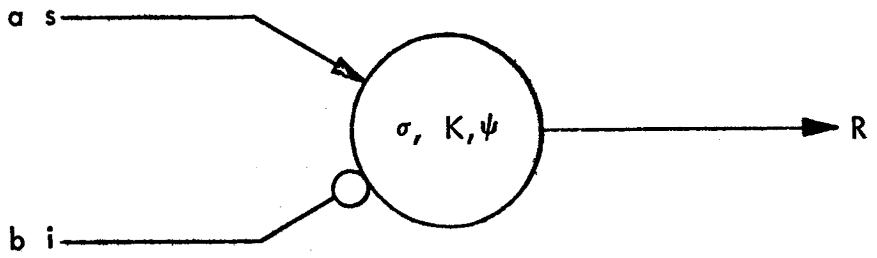
$$R = \min\left[\psi, \max(\rho, 0)\right]$$

3.4.3 Schematic Representation

All of the parameters introduced thus far can be shown in a schematic drawing of the data handling element (Figure 10). The figure is drawn using the notation of McCullough, Pitts, and Von Neumann.

The schematic to generate the max function is shown in Figure 11. In this drawing, the symbol for the threshold (σ) has been replaced with the value zero, and the gain (K) is given as unity. Later in this paper, it will be shown that a zero threshold and a unity gain can be realized with the non-numeric element.

As an aid to the reader, a verbal explanation of how the greater quantity, A or B, is produced at R will be given. First take the case when A is greater than B, and examine the output of the lower element. Since the inhibitory input, which is A, is greater than the stimulatory input B, a zero output is produced. Thus only A is introduced into the upper element, and therefore R equals A. For the case when B is greater than A, the output of the lower element is B minus A. When



s = STIMULATORY INPUT

i = INHIBITORY INPUT

a, b = WEIGHTING FACTORS

σ = THRESHOLD VALUE

K = GAIN FACTOR

ψ = SATURATION VALUE

R = RESPONSE

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Figure 10. Schemata for the Non-Numeric Data Handling Element

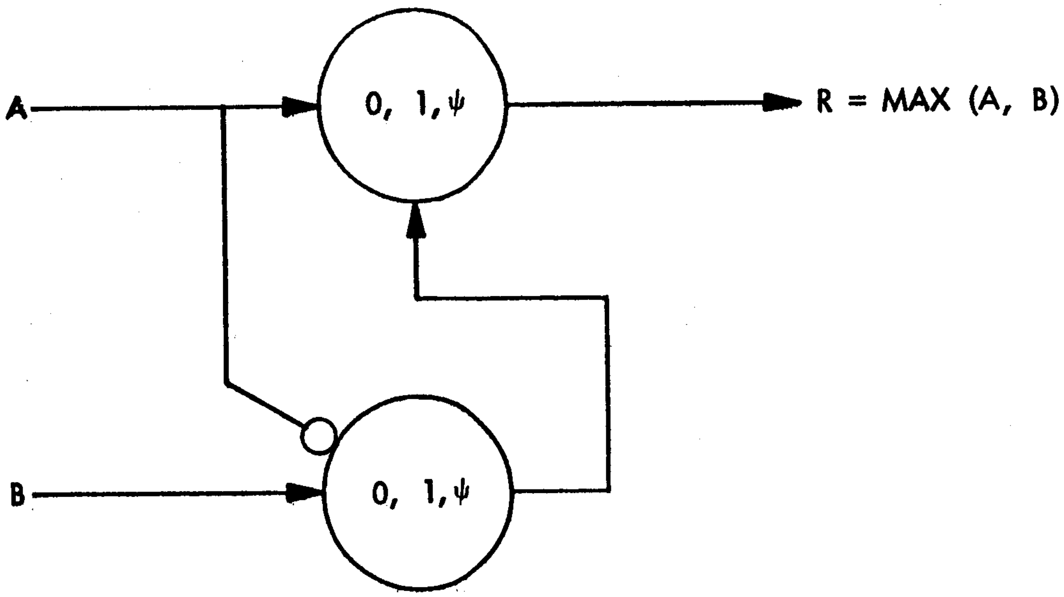


Figure 11. Generation of the Max Function

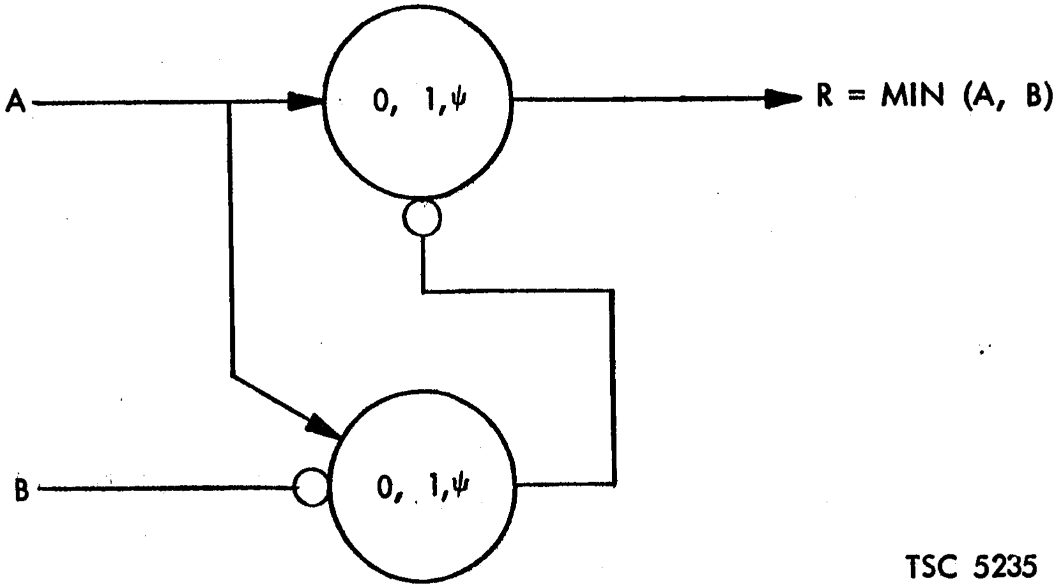


Figure 12. Generation of the Min Function

this is introduced into the upper element and added to A, a net output equal to B is produced. Thus for both cases, R will equal the greater value. The value of R will not be changed by reversing the inputs A and B.

A mathematical approach will be used in describing the generation of the min function (Figure 12). Again the inputs are symmetrical and a reversal of A and B will not affect the output.

Assume $A > B$

Lower Element, $R_L = \left[A - B - 0\right] 1 = A - B$

Upper Element, $R_U = \left[A - (A - B)\right] 1 = B$

Thus $R_U = B$

Assume $B > A$

$R_L = 0$

Thus $R_U = A$

$R_U = \min(A, B)$

3.4.4 Complement

If a variable A is bounded by zero (0) and some positive value (ψ), then the complement $(\bar{A})$ is given by $\psi - A$. Figure 13 shows the method of generation of the complement by the non-numeric data handling element.

3.4.5 Zero Threshold

Figure 14 indicates how the threshold value (σ) can be reduced to zero. The zero value for σ is produced by generating a constant equal to σ and supplying this value as a stimulus type input.

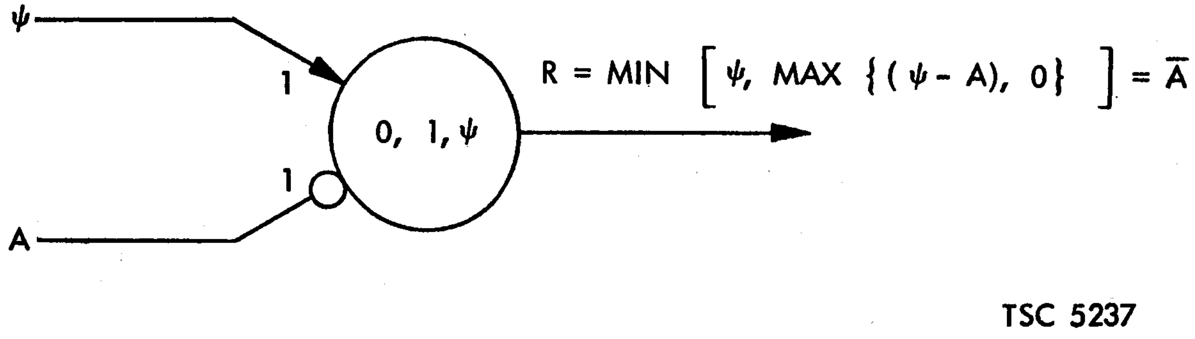


Figure 13 Generation of the Complement

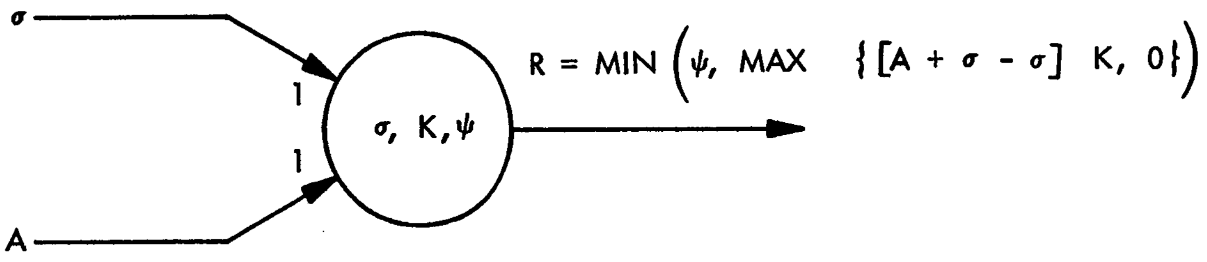


Figure 14. Reduction of Threshold to Zero

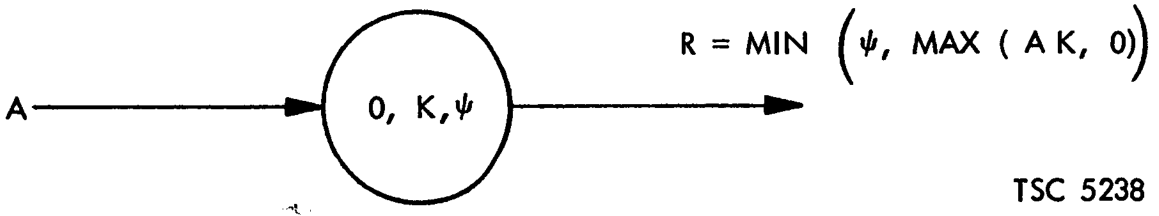


Figure 15. Zero Threshold Equivalent

An equivalent component configuration is shown in Figure 15.

3.4.6 Production of Unity Gain

The first step in producing unity gain (K = 1) is to use positive feedback as in Figure 16.

Consider the expression:

$$R = \min \left[\psi, \ \max A \left(\frac{K}{1 - K \sum_{i=1}^{n} P_i} \right), \ 0 \right]$$

If the term

$$\frac{K}{1 - K \sum_{i=1}^{n} P_i}$$

can be made to equal unit for all values of K, then the output (R) will appear to be produced by a unity gain.

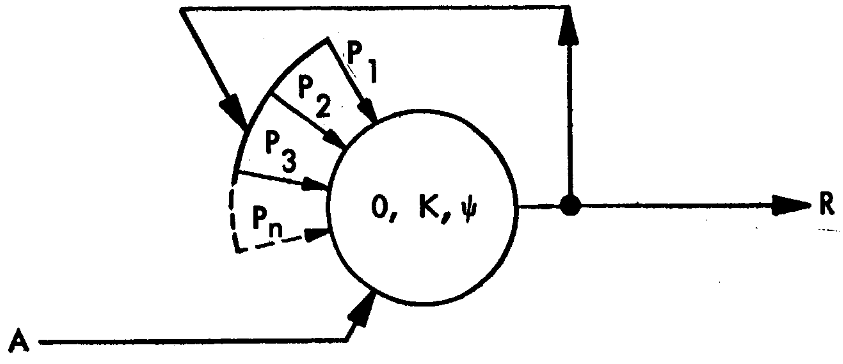


Figure 16. Positive Feedback

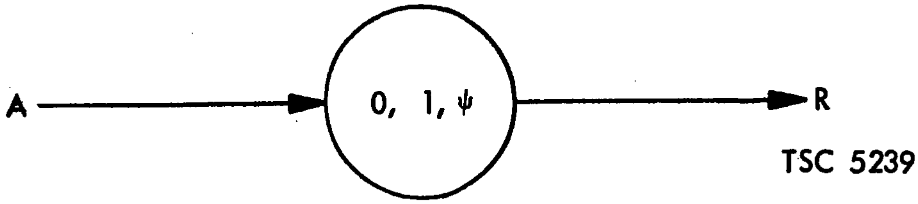


Figure 17. Equivalent Element With Unity Gain (K = 1)

The following table can be used to supply values that will make the term $\frac{K}{1 - K\sum_{i=1}^{n} P_i}$ equal to unity.

K	$\sum_{i=1}^{n} P_i$
0	∞
.1	9
.2	4
.3	2.333
.4	1.5
.5	1
.6	0.667
.7	0.429
.8	0.25
.9	0.111
1	0

A component that is equivalent to a non-numeric element with unity gain is given in Figure 17.

3.4.7 Mathematical Characteristics

A proof is next presented to implement the methods of manipulating the equations which result from the design of networks.

Theorem

$$\overline{\text{Max}(A, B)} = \text{Min}\overline{(A, B)} \text{ for } \psi_A = \psi_B = \psi$$

Proof

$$\overline{\text{Max}(A, B)} = \psi - \text{Max}(A, B)$$

For $A > B$ then

$$\psi - \text{Max}(A, B) = \psi - A = \overline{A}$$

For $B > A$

$$\psi - \text{Max}(A, B) = \psi - B = \overline{B}$$

Now if $A > B$ then $\psi - B > \psi - A$ or $\overline{B} > \overline{A}$

If $B > A$ then $\overline{A} > \overline{B}$

$$\therefore \overline{\text{Max}(A, B)} = \text{Min}\overline{(A, B)}$$

Similarly

$$\overline{\text{Min}(A, B)} = \text{Max}\overline{(A, B)} \text{ for } \psi_A = \psi_B = \psi$$

The restriction that $\psi_A = \psi_B = \psi$ is one which is not as serious as first appears. All that is implied by this restriction is that the complement is necessarily generated with respect to some value of ψ that represents a full-scale value for both variables.

A few definitions relating these functions are:

$$\text{Max}(A, \overline{A}) \geq \psi/2; \text{Min}(A, \overline{A}) \leq \psi/2$$

$$\text{Min}\left[\text{Max}(A, B), \text{Max}(\overline{A}, \overline{B})\right] = \text{Max}\left[\text{Min}(A, \overline{B}), \text{Min}(\overline{A}, B)\right]$$

$$\text{Min}\left[A, (\text{Max } B, C)\right] = \text{Max}\left[\text{Min}(A, B), \text{Min}(A, C)\right]$$

3.4.8 Graphical Technique for Two Variables

Let us approach the mathematics of the two variable non-numeric element through a graphical technique. For the case of a component with two inputs, a plane can be used by assigning one variable to each axis. By dividing the plane into sections, the regions where different inequalities hold may be easily seen (Figure 18). All of the eight regions shown in this figure may be recorded on one graph by means of superposition (Figure 19).

The graphical technique can be used as an aid to the analysis of a function. Consider the function:

$$\mathrm{Min}\left[\mathrm{Max}(A, B), \mathrm{Max}(\overline{A}, \overline{B})\right]$$

Using Figure 19, Max(A, B) and Max($\overline{A}$, $\overline{B}$) can be plotted (Figure Again referring back to Figure 19, the graphs of Max(A, B) and Max($\overline{A}$, $\overline{B}$) may be utilized to plot the function $\mathrm{Min}\left[\mathrm{Max}(A, B), \mathrm{Max}(\overline{A}, \overline{B})\right]$. See Figure 20.

A closer examination of the A-B plane is in order at this point. One important observation is that the diagonals and other lines drawn interior to the bounded portion of the plane can be described by an expression that is an equality. Figure 21 shows these lines and gives their equations.

If it is now assumed that any possible functions of A and B must be continuous across any boundary, then it is possible to construct all possible functions of A and B that can be synthesized with the non-numeric element. Utilizing Figure 19 and considering that the variable with the largest value in each region is in Level 1, enables us to construct a two-variable synthesis table (Table 3). The numbering of the regions is shown in Figure 19. To derive the Level 2 values, the second largest variable of each region is used. A similar procedure is used for Levels 3 and 4.

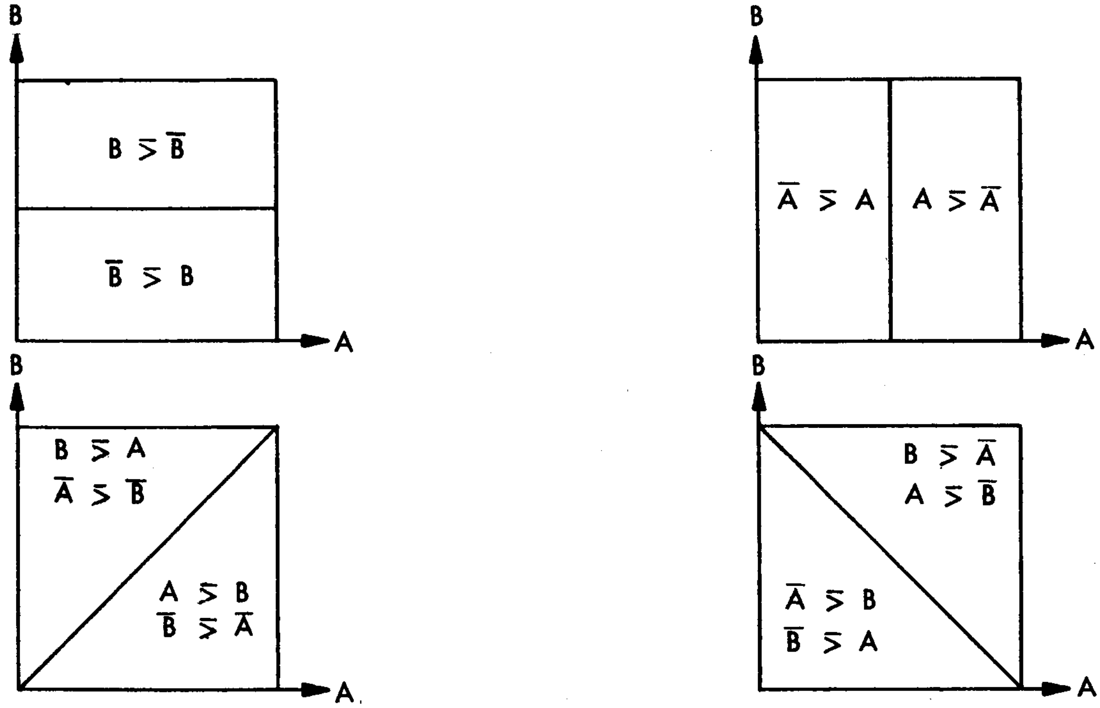
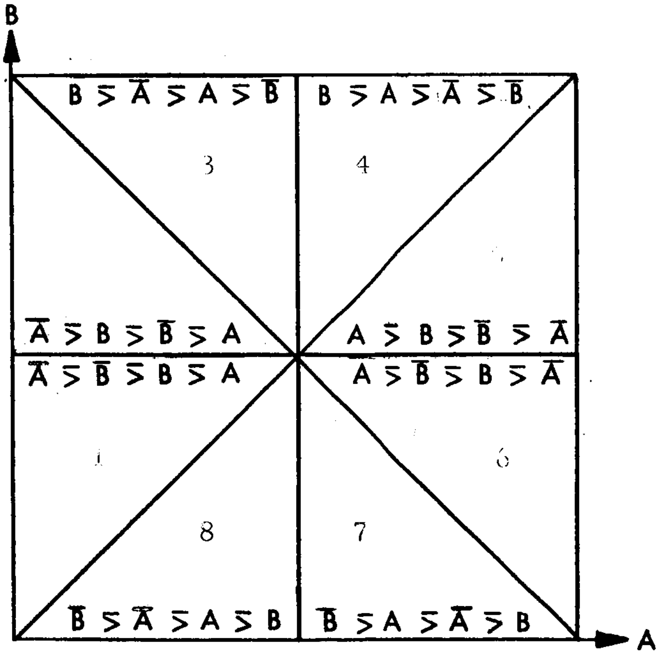


Figure 18. Pairs of Inequalities in the A-B Plane



(NUMBERS REPRESENT REGIONS)

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Figure 19. Composite of Inequalities

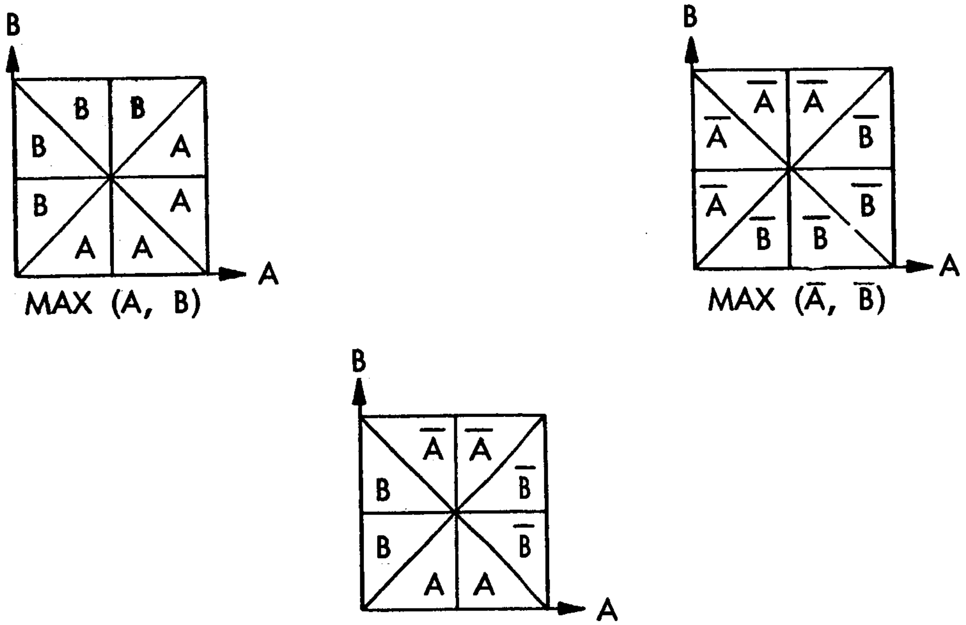
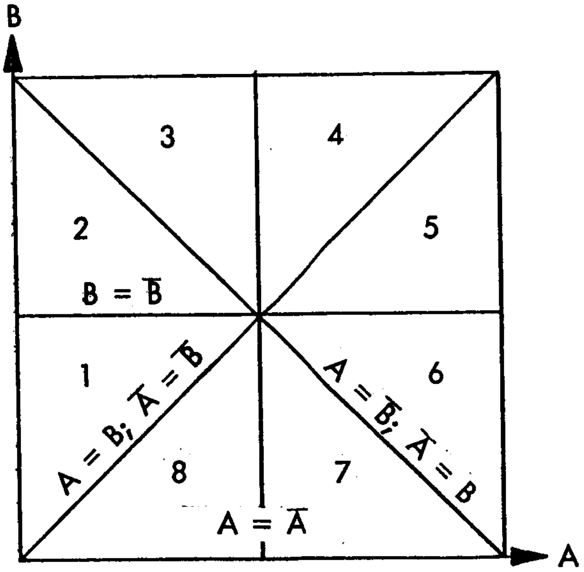


Figure 20

MIN [MAX (A, B), MAX (Ā, B̄)]

ANALYSIS OF FUNCTION:



(NUMBERS
REPRESENT
REGIONS)

Figure 21

CHARACTERISTICS OF THE A-B PLANE

Table 3.

Two-Variable Synthesis Table

REGION / LEVEL	1	2	3	4	5	6	7	8	COMMENTS	
1	$\bar{A}$	$\bar{A}$	B	B	A	A	$\bar{B}$	$\bar{B}$	MAX	
2	$\bar{B}$	B	$\bar{A}$	A	B	$\bar{B}$	A	$\bar{A}$	CENTERS MIN-MAX	CORNERS MAX-MIN
3	B	$\bar{B}$	A	$\bar{A}$	$\bar{B}$	B	$\bar{A}$	A	MAX-MIN	MIN-MAX
4	A	A	$\bar{B}$	$\bar{B}$	$\bar{A}$	$\bar{A}$	B	B	MIN	

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The column called "Comments" on Table 3 contains the terms "centers" and "corners". When a three dimensional plot of Figure 19 is constructed, then it will become apparent that the terms in Levels 2 and 3 are indeed either centers or corners. Centers are pairs of terms of the form

$$A \cdot \bar{A}, \quad B \cdot \bar{B}, \quad \bar{A} \cdot A, \quad \bar{B} \cdot B \ .$$

It can be seen that a dot has been used to denote center pairs. Corners are pairs of terms of the form

$$A \times \bar{B}, \quad \bar{A} \times B, \quad A \times B, \quad \bar{A} \times \bar{B} \ .$$

A cross has been used to denote corner pairs.

The remaining terms in the "Comments" column describe the kind of expression that is generated by a pair of variables of a particular Level.

3.4.9 Realizable Functions

As has been described, Table 3 was not developed by an arbitrary assignment of variables. Only certain sequences of variables can be mechanized by means of linear non-numeric data handling elements. The two-variable synthesis table serves as a chart to test the realizability of functions; for example, take the function $B, \bar{B}, \bar{B}, \bar{B}, \bar{A}, B, \bar{A}, A$. In checking for realizability the rules to be followed are:

A sequence is realizable if

1) The transition from one region to the next is made at the same level, or

2) The transition from one region to the next is made to the same variable at a different level.

Investigating the function above, it will be found that the transition from region 5 to region 6 is invalid, and thus the sequence is not realizable with linear elements. These functions can be developed by the use of a special feedback network that is shown under the section describing memory in the third quarterly report.

With two variables, A and B, that can each be given in the normal or complemented state, there are four possible levels for each region. Since there are eight regions, there are 4^8 or 65, 536 possible functions that can be generated. **Utilizing Table 3, only about 100 of these will be** found to be simply realizable. These functions will be called linear while the remaining non-realizable sequences will be denoted as non-linear.

3.4.10 Example of the Synthesis of a Function

As an example, let us take the function $\bar{A}, \bar{A}, \bar{A}, A, B, \bar{B}, A, \bar{A}$, Using Table 3, the variables can be arranged by levels and grouped into adjacent pairs.

Level				
1	$\bar{A}, \bar{A}$			
2		$\bar{A}, A$	$B, \bar{B}$	$A, \bar{A}$
3				
4				

Now the symbology used to denote centers and corners can be applied.

Levels				
1	$\bar{A} \cdot \bar{A}$			
2		$\bar{A} \cdot A$	$B \cdot \bar{B}$	$A \cdot \bar{A}$
3				
4				

Now the "Comments" column of Table 3 should be noted. It will be seen that Level 1 terms are of the max form, while Level 2 and 3 terms can be either min-max or max-min, and Level 4 is of the min form. Referring to the chart above, and the rules for form, the equation can be directly written as

$$\text{Max}\left[\underset{\substack{\uparrow\\ \text{Level 1}}}{\bar{A}},\ \text{Min}\left\{\text{Max}(\underset{\substack{\uparrow\\ \text{Level 2}}}{\bar{A}},\ A),\ \text{Max}(\underset{\substack{\uparrow\\ \text{Level 2}}}{B},\ \bar{B})\right\}\right]$$

The equation can be checked by straightforward analysis by the use of Figure 19.

	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
$\text{Max}(\bar{A},\ A)$	$\bar{A}$	$\bar{A}$	$\bar{A}$	A	A	A	A	$\bar{A}$
$\text{Max}(B,\ \bar{B})$	$\bar{B}$	B	B	B	B	$\bar{B}$	$\bar{B}$	$\bar{B}$
$\text{Min}\left[\text{Max}(\bar{A},\ B),\ \text{Max}(B,\ \bar{B})\right]$	$\bar{B}$	B	$\bar{A}$	A	B	$\bar{B}$	A	$\bar{A}$
$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$
$\text{Max}\left[\bar{A},\ \text{Min}\left\{\text{Max}(A,\ \bar{A}),\ \text{Max}(B, \bar{B})\right\}\right]$	$\bar{A}$	$\bar{A}$	$\bar{A}$	A	B	$\bar{B}$	A	$\bar{A}$

The mechanization of this equation using the max-min grouping of non-numeric components is shown in Figure 22.

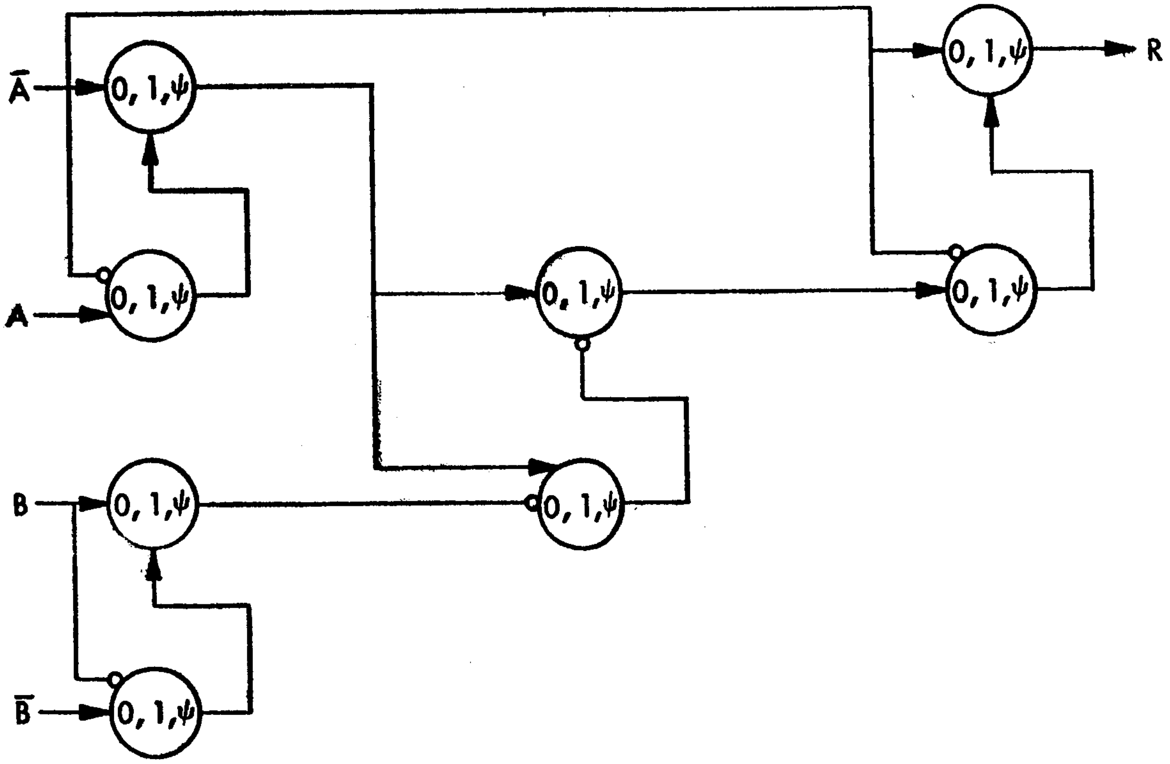

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Figure 22.

MECHANIZATION OF THE FUNCTION

$$R = \mathrm{MAX}\left[\bar{A},\ \mathrm{MIN}\ \{(\mathrm{MAX}\ (A,\ \bar{A}),\ \mathrm{MAX}\ (B,\ \bar{B})\}\right]$$

Several additional sequences have been synthesized and are presented along with their equations. The synthesis procedure just described was used, and, if the reader cares to, he should be able to derive these in the form shown or one that can be proven equivalent by analysis.

1. $\bar{A}\ \bar{A}\ B\ B\ A\ \bar{B}\ \bar{B}$

$$\text{Max}(\bar{A}\ \ B\ \ A\ \ \bar{B})$$

2. $\bar{B}\ B\ \bar{A}\ A\ B\ \bar{B}\ A\ \bar{A}$

$$(\text{Min}(\text{Max } B\ \bar{B},\ \text{Max } \bar{A}\ A) \text{ or } \text{Max}(\text{Min } B\ \bar{A},\ \text{Min } A\ B,\ \text{Min } A\ \bar{B},\ \text{Min } \bar{A}\ \bar{B})$$

3. $B\ \bar{B}\ A\ \bar{A}\ \bar{B}\ B\ \bar{A}\ A$

$$\text{Max}(\text{Min } B\ \bar{B},\ \text{Min } A\ \bar{A}) \text{ or } \text{Min}(\text{Max } \bar{A}\ B,\ \text{Max } A\ B,\ \text{Max } A\ \bar{B},\ \text{Max } \bar{A}\ \bar{B})$$

4. $A\ A\ \bar{B}\ \bar{B}\ \bar{A}\ \bar{A}\ B\ B$

$$\text{Min}(A\ \ B\ \ \bar{B}\ \ \bar{A})$$

5. $\bar{B}\ B\ \bar{A}\ \bar{A}\ \bar{B}\ B\ \bar{A}\ \bar{A}$

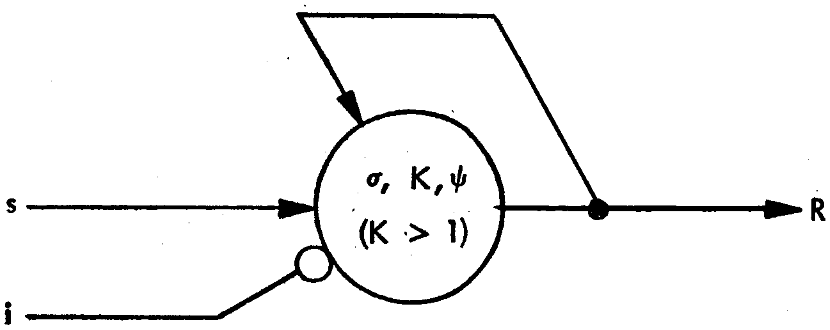
$$\text{Max}\left[0,\ \text{Max}\left[\text{Min } \bar{A}\ \bar{B},\ \text{Min } \bar{A}\ B,\ \text{Min}(\text{Max } \bar{A}\ B,\ \text{Max } \bar{B}\ \bar{A})\right]\right.$$

3.4.11 Memory

Through the use of feedback in a non-numeric element, it is possible to create an active component with a memory (Figure 2). When the output pulse repetition rate from this component is in excess of the input pulse repetition rate, a feedback loop may be used to route enough stimulus back to the input so that a continuous stream of output pulses of full scale value will be maintained. The inhibitory input will stop the self-regenerative oscillations and destroy that which has been stored.

Before developing, to its fullest extent, the concept of how a non-numeric data handling system operates, it is important to recognize how information is presented to such a system for manipulation. Returning to the neuron, we find that there are only two ways in which information can be presented. The first is to distribute spacially one attribute of a generalized input signal, or second to produce at discrete points in the information space, time varying data. To make a specific example, the ear distributes frequencies in a spacial fashion at the site of the cochlea and commumicates intensity informaion by causing temporal variation in evoked pulse repetition rates.

The picture that should be kept in mind is of a region of space which contains a finite number of specified data points. One aspect of information is conveyed by the absence or presence of activity over the entire region of space thus defined, coupled with the unique pattern of the activity. A second aspect of information content is found by examination of individual points that are considered as time varying entities.



WHEN $s > \sigma$, THEN $R = \psi$ UNTIL

$i > \psi - \sigma$, THEN $R = 0$

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Figure 23. Memory Element

The non-numeric data handling element has demonstratable properties of memory. The fact that the element can be excited or not implies that information of a spacial type can be stored. That is, a point in the memory space either has activity associated with it or it does not. The non-numeric data handling system does not store temporal information and must convert a temporal situation to a spacial one. Referring then to the analogy of hearing and sound, it is apparent that frequencies are recorded in a straightforward manner by virtue of spacial distribution, but intensity or loudness is not.

It is an interesting side note that a human can recognize the sound of an instrument such as a trumpet as distinguished from a clarinet because he has stored the spacial distribution of frequencies present. If, however, one were to ask the human to recall the loudness of a trumpet versus the loudness of a clarinet, the ability to distinguish with such a degree of fineness is evidentally lacking. The conversion from temporal information flow to spacial is, of necessity, a coarse one exhibiting large amounts of granularity.

In principle, the operation of the non-numeric data handling system follows a set of fairly simple rules for manipulating data. The end result being the production of outputs which are a consequence of present plus past inputs to the system. The outputs of such a system will, of course, be in the same format, namely, spacial distribution of activity and specific amounts of activity at various locations and must suitably be coupled back into the environment into which the system is to operate. Perhaps the most interesting aspect of the system is the mechanization whereby past inputs affect the operation of present outputs.

The memory portion of the non-numeric system is composed of what will be termed memory planes. These planes are defined in terms of the interrogation system which is used to read out of and enter new information into these planes. The interrogation signal propagates via a branching network such that at a given instant of time, the interrogation signal has arrived at certain locations within the network. All memory elements stimulated at this location are said to be contained in that particular memory plane. It is important to recognize that the plane is not a prearranged entity but is a surface defined by propagation delays in the interrogation network. Moreover, it is not critical that the propagation delays be exactly maintained in the interrogation network, a principle which will, of necessity, be required over and over again in the conceptual design of the non-numeric data handling system.

Within these memory planes there are large numbers of the memory units shown in Figure 23. As the interrogation pulse or activity levels arrive at a particular memory plane, all information stored within that plane is allowed to pass through a network which will be termed the readout network from the memory. A particular spacial location in one memory plane is defined as being identical in a second memory plane if in the readout network, activity in these two points evokes a response in a common element of the readout network. The method whereby the information is read from the memory is to take the min function of the interrogation signal and the memory signal, remembering, of course, that the memory contains either the full-scale output ψ or 0. Appearing then on the readout lines are a succession of spacial patterns, each pattern corresponding to one of the memory planes.

3.4.12 Correlation

Attention now is turned to incoming patterns which are being presented to the system as new data. This new data is presented via several channels or input sensors and the object is to, in a continuous fashion, attempt to find a correlation of sufficient magnitude between stored data and incoming data, either in part or in total. Each sensor has associated with it, a sensor plane on the surface of which is displayed the appropriate spacial pattern. A secondary plane associated with the sensor contains the converted temporal information, once again appearing as a spacial pattern.

Both the memory patterns and the sensor patterns are made available to a correlator system which generates an output that varies temporally with the level of correlation between the memory and input pattern. The correlation operation once again makes use of the min function. Applying this min function point by point and then summing the level of activity from all points, provides an output whose pulse repetition frequency varies directly as the degree of association in the two spacial patterns. A threshold is established such that correlation levels that are always below a critical threshold are recognized input patterns that do not have a similar pattern in memory and are therefore new experiences for the system. Any time the threshold is exceeded, however, the system recognizes the stimulus as having occurred in the past and it is recognized as a stored memory plane.

When a new pattern is presented to the system, the sensor pattern is transferred to temporary storage to await the progression of the interrogation pulse to an as yet unused portion of the memory, whereupon, this pattern is entered as a new input to the memory system. If, on the other hand, a high level of correlation is achieved in any of the major sensor areas with a stored pattern, the stored pattern is modified by addition of any new information contained in the input sensor pattern. This is accomplished by taking the max function of both the memory and the stored pattern. The modified pattern is then re-entered into the memory at the location where it originated. This new location is found by utilization once again of the correlator. One possible degree of sophistication can be added to the system in the form of a censor inserted in the rewrite portion of the system. This censor serves in the role of testing the newly formed pattern for contradiction of any stored patterns in the memory.

3.4.13 Mechanization of a Correlator

In order to mechanize a correlator, it is first necessary to describe the transformation of the incoming information signal in a non-numeric data handling system. An entering stimulus can have many different properties; for example, a visual stimulus can be said to have the properties of intensity, color, shape, motion, etc. Each of these properties undergoes an invarient transformation into a spacial pattern that is temporarily displayed in an information plane. By invarient, it is meant that the transformations are made without regard to the overall visual scene. Only the property that is being transformed is considered while the remainder of the natural stimulus is ignored.

A schematic representation of a transformation from a visual stimulus to a spacial pattern is shown in Figure 24. In order to provide a simple example, an information plane pattern with only four points was

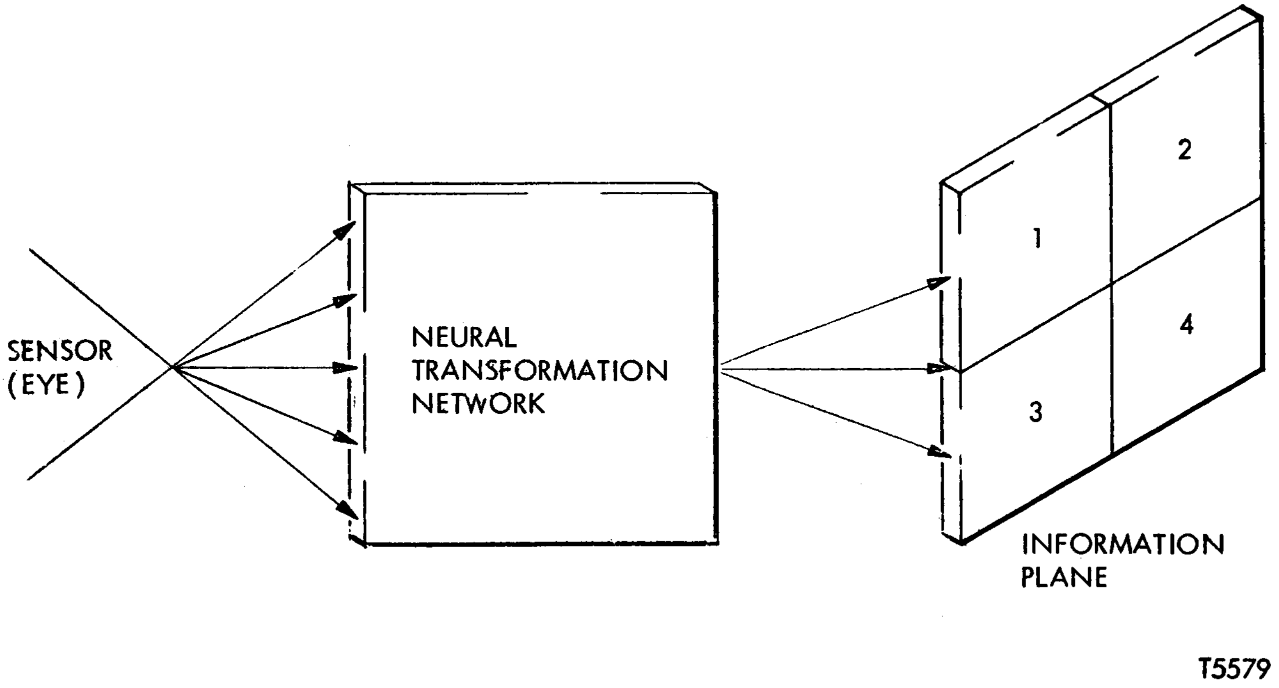


Figure 24. Transformation of Stimuli Into a Spacial Pattern

selected. Each of the spaces may be in an active or a not active state. As an illustrative example, the transformation of the two visual properties of intensity and red-blue color will be examined. An assignment of increasing intensity and changing hue may be made on the transformation pattern, as is shown in Figure 25. Many combinations of intensity and hue can be mapped on the information planes as Figure 25 indicates.

Assuming the format of the data in the information plane is as given in Figure 25, the procedure of operation of the correlator can be described. Let the transformed spacial pattern obtained from a stimulus be called the information plane, while previously stored patterns can be called memory planes. The purpose of the correlator is to compare the information plane with the memory planes in order to ascertain if a stimulus is similar to a previously stored pattern.

It is expected that actual planes will be fairly large in spacial capacity, and that a correlator carries out a complete comparison between the information plane and the various stored memory planes. A portion of these overall planes may be concerned with light intensity and color. An example of such a small plane can be examined by utilizing the patterns of Figure 25.

A correlator using non-numeric data handling elements is mechanized as shown in Figure 26 This figure shows the spacial data of a stimulus entering from the information plane and the stored data entering from the memory planes. Two symmetrically fed non-numeric elements receive this data and transmit it to the inhibitory input of a third element. The third element receives an excitatory stimulus that is constant. This

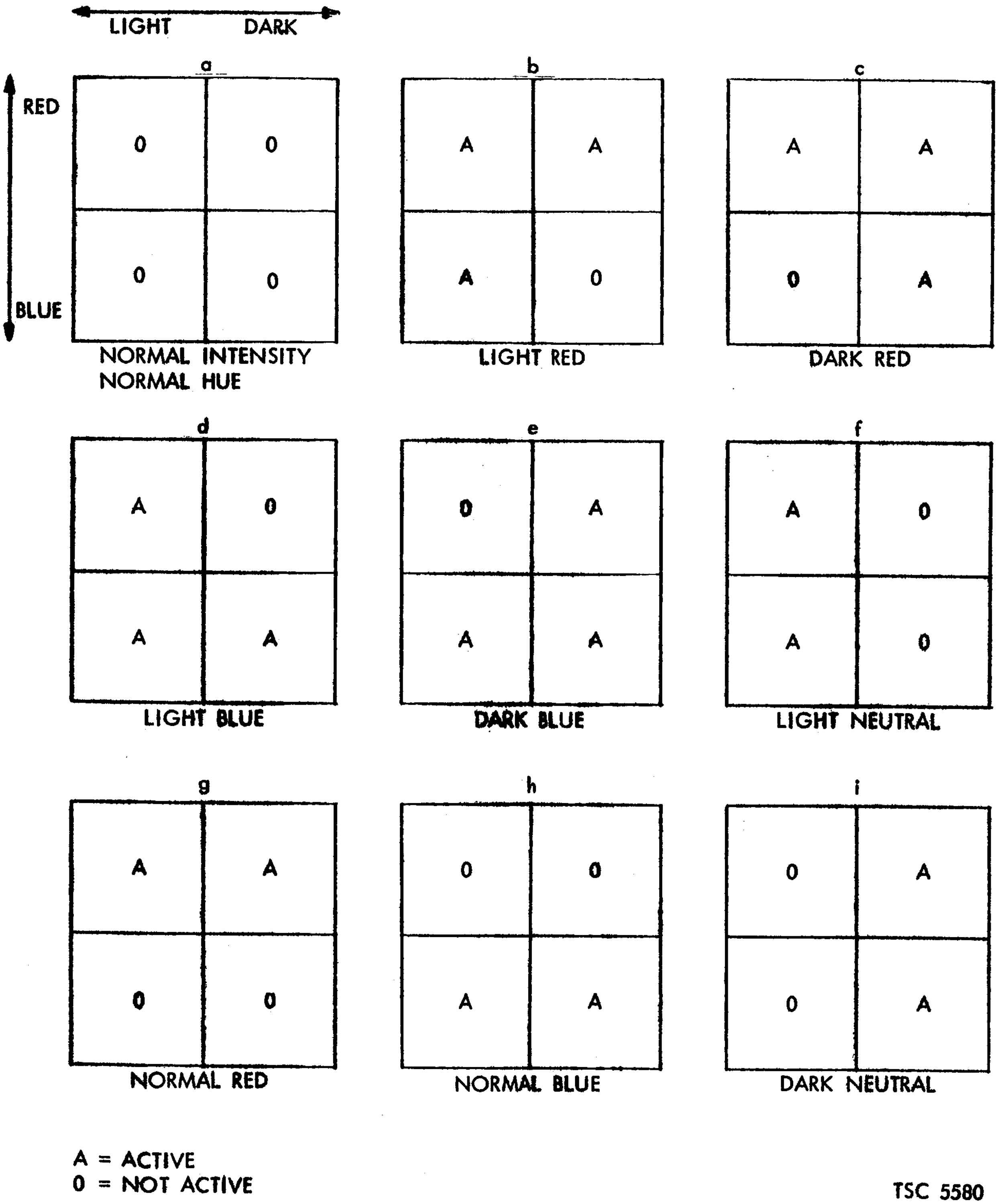
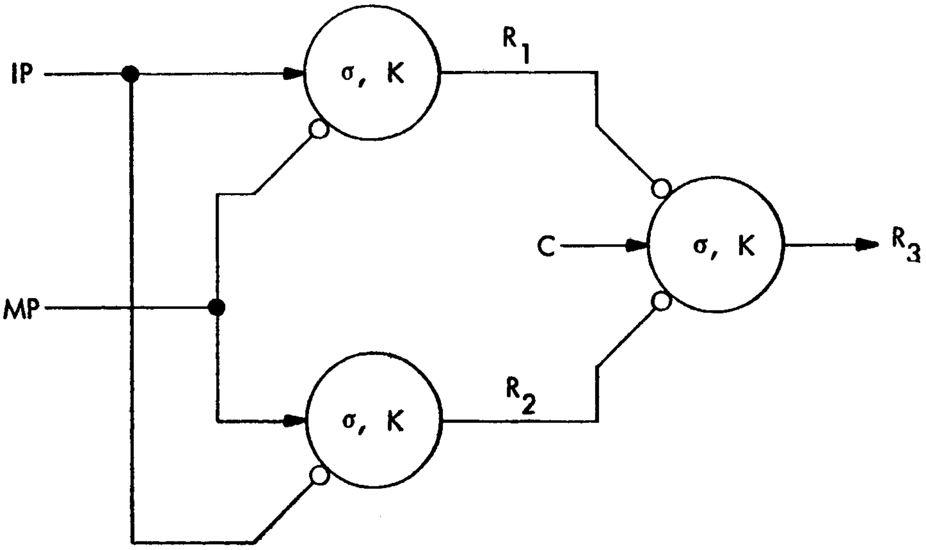


Figure 25 Transformation Planes for Two Properties



$$R_1 = \mathrm{MAX}\left(0,\ \mathrm{MIN}\left\{\psi,\ \left[IP - MP - \sigma\right]K\right\}\right)$$

$$R_2 = \mathrm{MAX}\left(0,\ \mathrm{MIN}\left\{\psi,\ \left[MP - IP - \sigma\right]K\right\}\right)$$

$$R_3 = \mathrm{MAX}\left(0,\ \mathrm{MIN}\left\{\psi,\ \left[C - R_1 - R_2 - \sigma\right]K\right\}\right)$$

IP = INFORMATION PLANE
MP = MEMORY PLANE
C = CONSTANT
R = RESPONSE

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Figure 26. Mechanization of Correlator

correlator compares the information plane and the memory plane. A larger group of non-numeric data handling elements can be used to form a correlator system that is capable of comparing a larger transformation plane (Figure 27).

To clarity the operation of the correlator system of Figure Z, the steps in the process of finding the stored memory plane that is the most similar to a stimulus will be outlined. As a stimulus, it can be assumed that a dark-red visual input is transformed into a spacial pattern on an information plane. Now the correlator must compare all of the memory planes concerned with intensity and hue against the information plane. The planes of Figure 25 will be used as the memory planes, and the information planes will be taken as Figure 25c.

Values can be assigned to the states of each space within a plane and to the other variables of the correlator system. A convenient weighting is the following (see Figures 25a and 27)

A = activity = 10 units

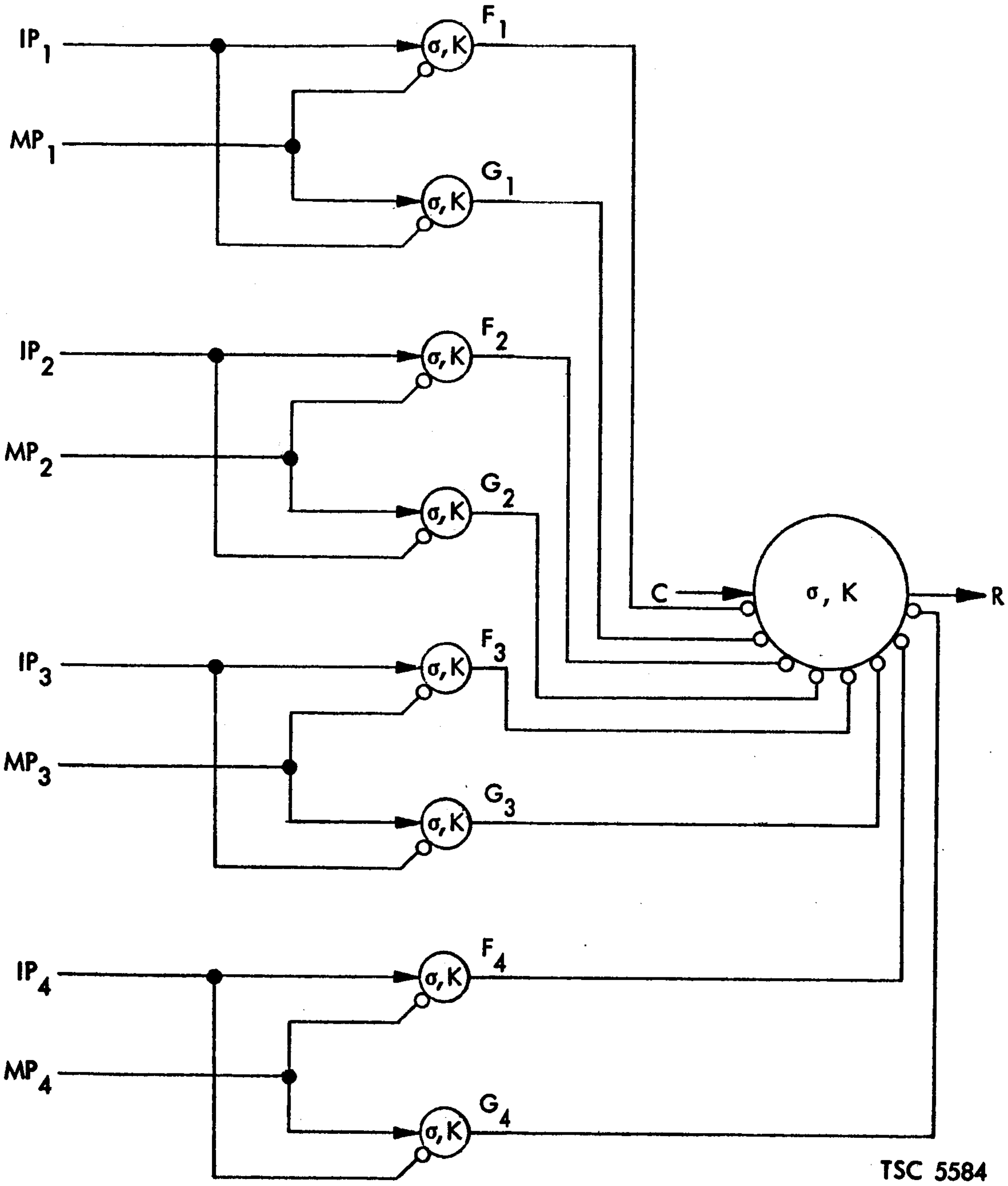
O = no activity = 0 units

c = 40 units

σ = 2 units

K = 1

A clear way to show the operation of the correlator system is by means of Table 4. The equation for the response of a non-numeric data handling element is used to derive the value of the output response R. The basis for this response function is shown at the end of Table 4.



IP = INFORMATION PLANE
MP = MEMORY PLANE
σ = THRESHOLD VALUE
K = GAIN
C = CONSTANT
R = RESPONSE

Figure 27. Two Property Correlator System

Table 4.
Steps in the Operation of the Correlator

Number of Space	Value of IP Space	Value of MP Space	Value at F	Value at G	Response R
	(Dark Red)	(Normal Intensity, Normal Hue)			
1	10	0	8	0	14
2	10	0	8	0	
3	0	0	0	0	
4	10	0	8	0	
			$\Sigma F = 24$	$\Sigma G = 0$	
			$\Sigma F + \Sigma G = 24$		
	(Dark Red)	(Light Red)			
1	10	10	0	0	22
2	10	10	0	0	
3	0	10	0	8	
4	10	0	8	0	
			$\Sigma F = 8$	$\Sigma G = 8$	
			$\Sigma F + \Sigma G = 16$		
	(Dark Red)	(Dark Red)			
1	10	10	0	0	38
2	10	10	0	0	
3	0	0	0	0	
4	10	10	0	0	
			$\Sigma F = 0$	$\Sigma G = 0$	
			$\Sigma F + \Sigma G = 0$		
	(Dark Red)	(Light Blue)			
1	10	10	0	0	22
2	10	0	8	0	
3	0	10	0	8	
4	10	10	0	0	
			$\Sigma F = 8$	$\Sigma G = 8$	
			$\Sigma F + \Sigma G = 16$		

$$\rho = \left[\sum_{j=1}^{n} a_j s_j - \sum_{j=1}^{m} b_j i_g - o \right] K$$

$$R = \max \left[\rho, o \right]$$

For the present case, a = b = 1. This equation has been previously presented in Section 3. 4. 2.

In a manner similar to that of Table 4, the remaining five values of response can be obtained from the correlator. Figure 28a is a plot of the outputs of the correlator system for the given parameters.

If the values of the information plane (in this example, dark red), are multiplied by two while the memory plane values remain as previously assigned and the constant (C) is changed to 80 units, the output response shown in Figure 28b is obtained. It may be seen that this plot rises and falls as Figure 28a, but there is no linear relationship between the two.

A linear relationship can be obtained by making the values of both the information and memory plane states equal (A = 10 units, 0 = 0 units), and by setting the gain factor (K) equal to two for the two symmetrical elements. Thus Figures 28a and 28c can be seen to be linearly related. It may be noted that increasing the gain factor causes the output of the correlator to peak more sharply.

All that remains in order to select the memory plane that has the highest correlation with the information plane is to choose the maximum output of the correlator.

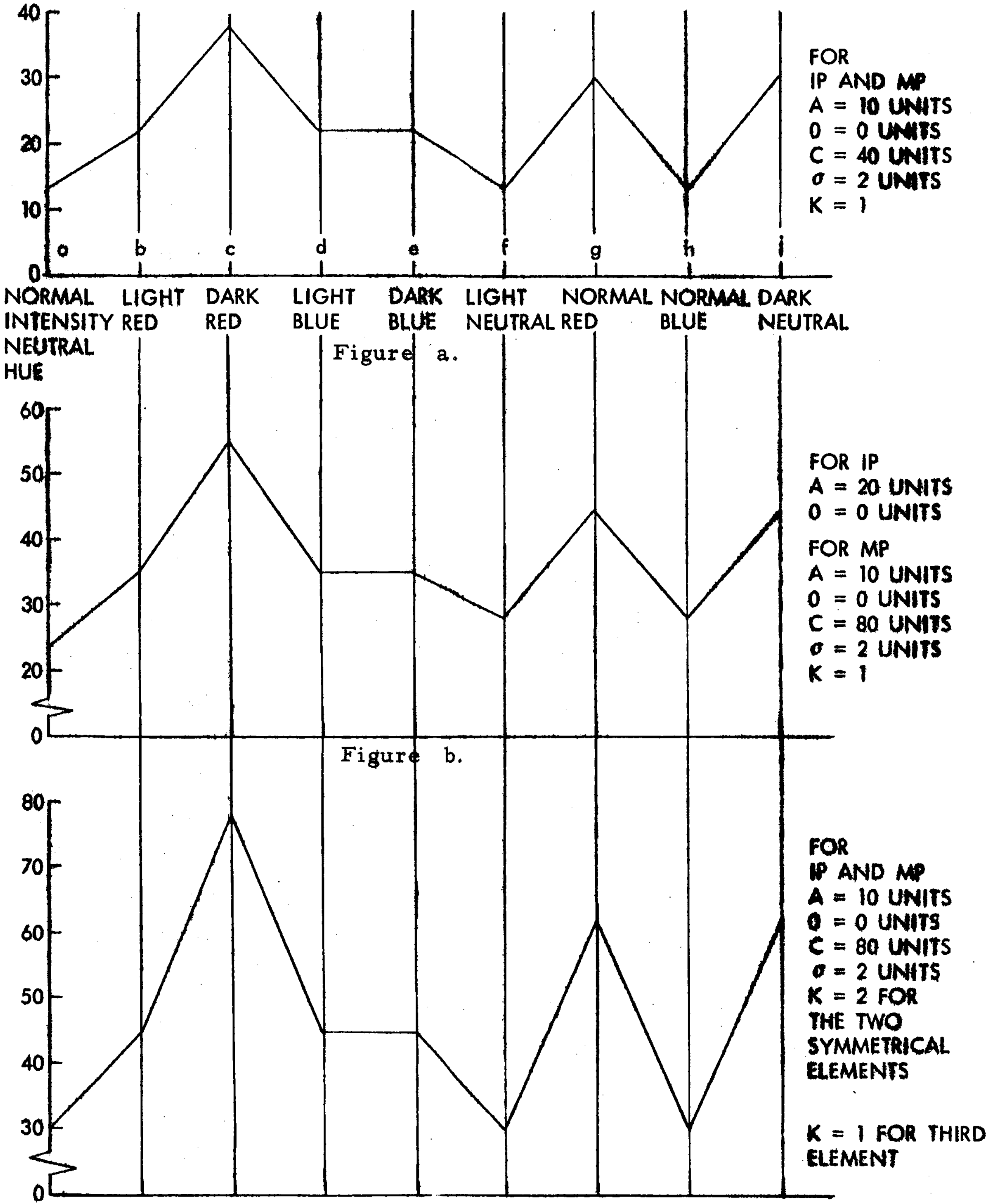


Figure a.

Figure b.

Figure c.

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Figure 28. Output of the Correlator System for a Dark Red Stimulus

3.4.14 Derivation of Transformations for a Four-Region Information Plane

In Figure 29the operational relationships of two transducers are shown in graphical form. Instead of using the colors red and blue, a nomenclature change to warm and cold (hue) respectively has been made. Halfway between cold and warm is a neutral hue that represents medium activity. Hue will be represented by the variable B.

Intensity description will remain as previously used with a completely dark input producing no activity and a very light input producing maximum activity. The variable A will be used to represent intensity.

Now a derivation of the transformation networks that convert sensory data into a four space information plane can be made. The derivation begins by writing out the sensory responses for light-warm (L-W), dark warm (D-W), light cold (L-C), and dark cold (D-C). Using the graphs of activity of Figure , the four sensory responses can be charted as in Figure . As an example, the light-warm chart will be explained. The variable A is used to show that the activity is light, and, thus, square R_3 and half of R_1 contain A. The other half of R_1 contains B, since this is the variable for warm, and square R_2 also contains B. Because the activity is neither cold nor dark, square R_4 contains the complement of square R_1.

In the lower left plot of Figure 30, a compilation of the data in square R_1 of the four previous plots is made. When A and B are both high, the response is light and warm and the R_1 square of L-W is used twice in the upper right hand portion of the compilation plot. If A is high and B is low, the response is light and cold and the R_1 square of L-C is used twice in the

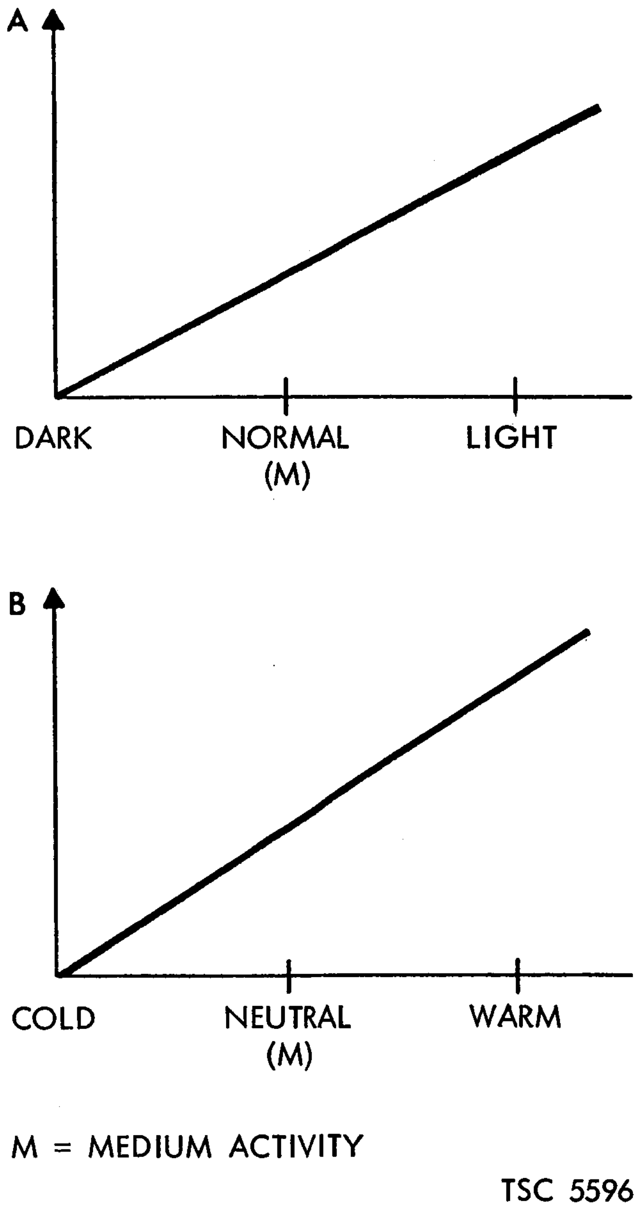


Figure 29. Operational Relationships of the Dark-Light and Cold-Warm Transducers

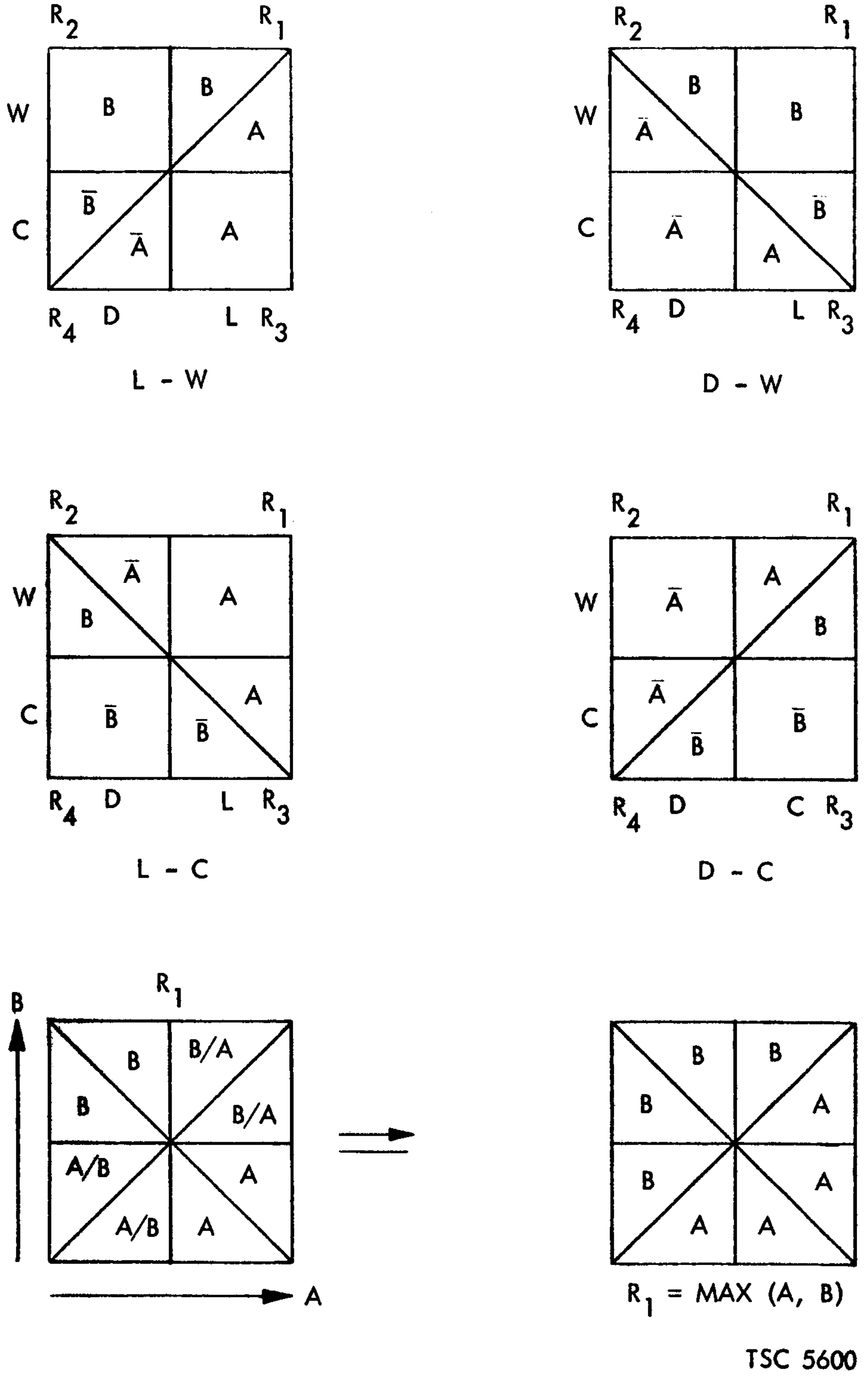


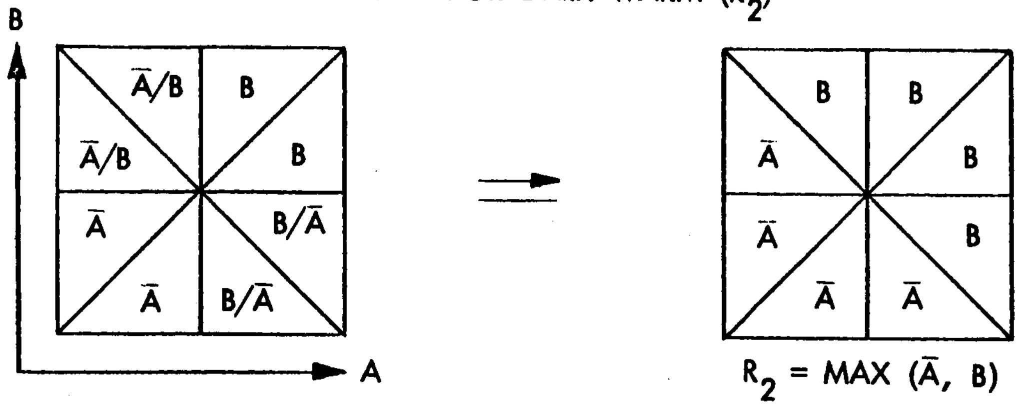
Figure 30. Derivation of Network for Light Warm (R_1)

lower right hand portion of the compilation plot. Now in order to decide which variable to use in each of the light regions of the compilation plot, the figure entitled "Composite of Inequalities" in Section 3. 4. 8 is utilized. The greater value in each region is then chosen. Again referring to this figure, it can easily be seen that the plot in the lower right hand corner of Figure 30 is Max (A, B).

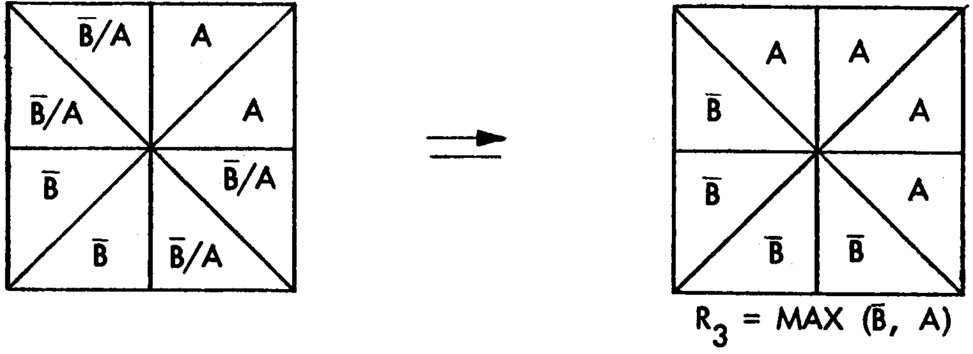
In exactly the same manner, R_2, R_3, and R_4 transformation networks are synthesized. Figure 31 shows the eight regions of response of each point in the information plane for these three networks. Figure 32 serves as a summary of the network equations derived in Figures 30 and 31

The following discussion is presented to briefly summarize what has been done to this point. In order to make information available to a correlator from some external stimulus for comparison with memory planes of stored previous stimuli, it was found necessary to sense the stimulus (hot-cold, light-dark), and develop invarient transformation networks for generation of the information plane. The information plane is comprised of the four spacial points R_1, R_2, R_3 and R_4. Each of these points are the outputs of a simple transformation network. Each network is generated by the simple Max function generator. Thus, the points R_1 - R_4 are in a form suitable for use as points IP_1 - IP_4 in Figure 27.

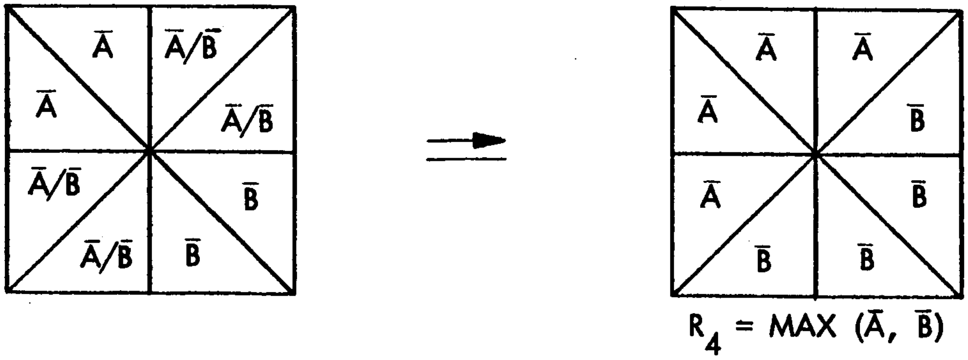
In Figure 33 an analysis is presented for the conditions that will result when continuous variables A and B are made to take on midpoint values (normal brightness or neutral hue). These cases are shown for the sake of completeness, since the outputs produced are completely defined by the equations R_1 - R_4 already derived. It is interesting to note that when the four conditions of Figure 32 and the five special cases of Figure 33 are compared to the nine conditions of Figure 25, there is a one-to-one correspondence of transformation planes.



NETWORK FOR DARK-WARM (R_2)



NETWORK FOR LIGHT COLD (R_3)



NETWORK FOR DARK-COLD (R_4)

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Figure 31 Networks for R_2, R_3, and R_4

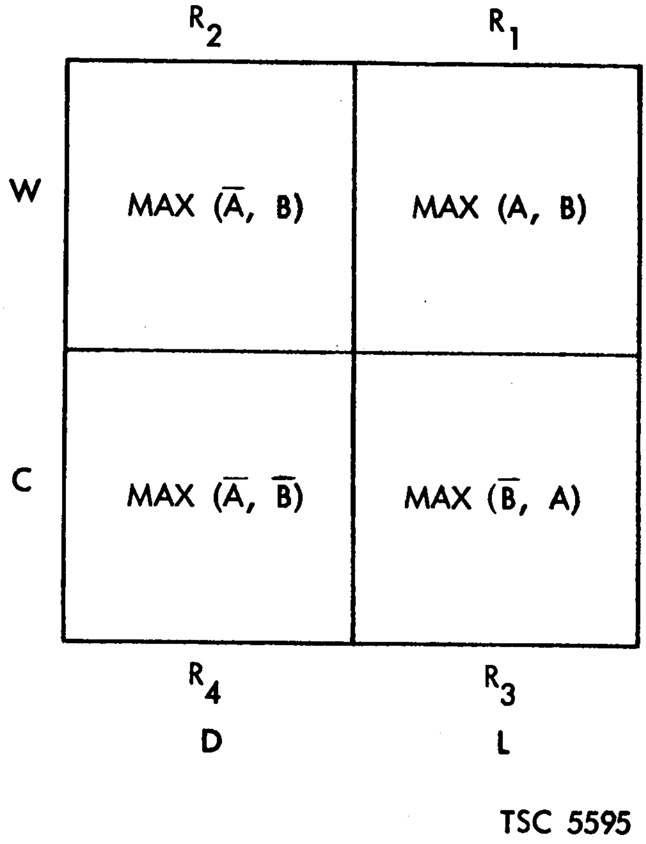

Figure 32. Summary of Transformations for R_1, R_2, R_3, and R_4

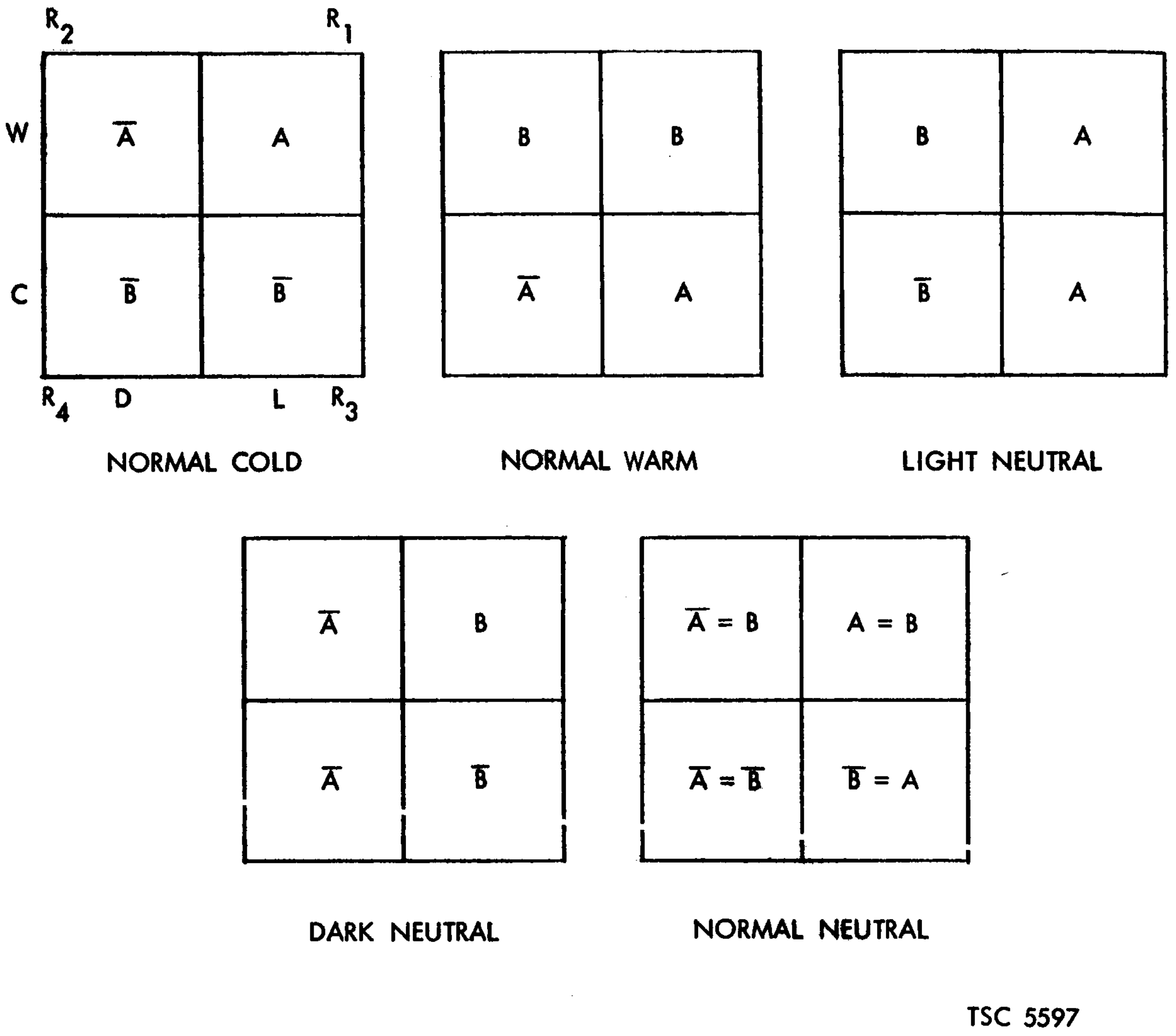

Figure 33. Transformations for Midpoint Values of Stimuli

As an example of the derivation of Figure 33, the normal cold case is analyzed as follows:

By reference to Figures 29 and 32,

$$A = \overline{A}, \quad \overline{B} > A = \overline{A} > B$$

$$R_1 = \mathrm{Max}\,(A, B) = A$$

$$R_2 = \mathrm{Max}\,(\overline{A}, B) = \overline{A}$$

$$R_3 = \mathrm{Max}\,(\overline{B}, A) = \overline{B}$$

$$R_4 = \mathrm{Max}\,(\overline{A}, \overline{B}) = \overline{B}$$

This is shown in the upper left case of Figure 33.

The action of the four networks is clearly shown by reference to the three dimensional plot shown in Figure 34. Each region R_1 - R_4 is shown with response plotted in the vertical direction. Inspection of this plot sheds new light on the way in which the transformations have been made. In the upper drawing of Figure 34, region R_1 is greater than or equal to any other region. This immediately indicates that the stimulus is either light of warm or both. Region R_2 being large indicates that either the stimulus is dark or warm or both. Since it cannot be dark and light simultaneously, the conclusion obtained from R_1 and R_2 is that it is warm and either light or dark. Region R_3 and R_4 indicate that the stimulus is more light and cold or both then it is dark and cold or both. Since it was already decided that the stimulus is warm, then it is lighter then it is dark. Thus, it is warm and light. Finally, R_1 and R_3 show that the activity of the warm transducer is greater than the activity of the light transducer.

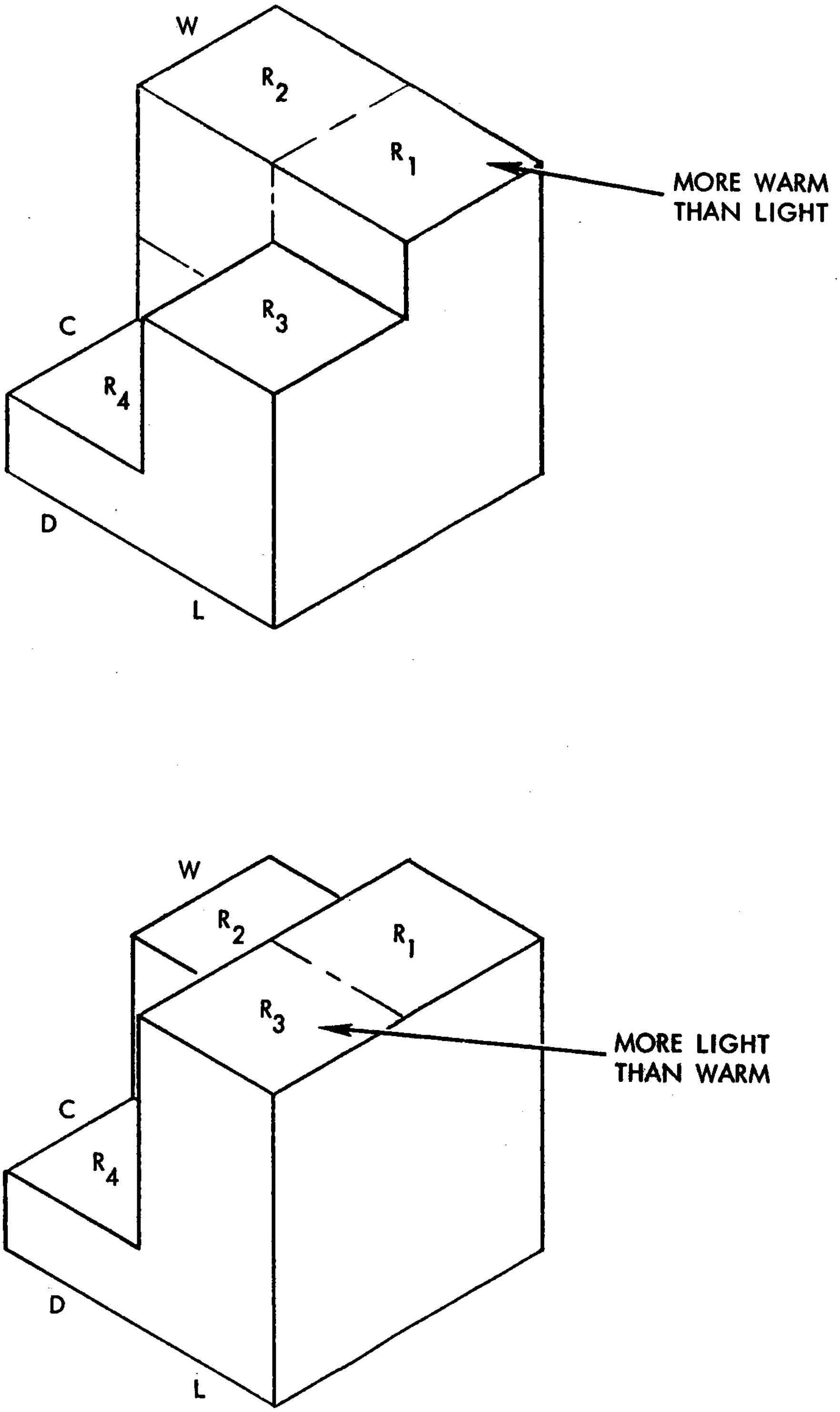

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Figure 34. Three Dimensional Plot of Regions R_1-R_4

The lower drawing in Figure 34 shows the case with activity higher in the light transducer than in the warm transducer.

3.4.15 Derivation of Transformations for a Three-Region Information Plane

It is possible to use a three point information plane, but, as might be suspected, the price paid for this reduction in spacial distribution is paid for by increased complexity in the networks needed to transform the transducer inputs to a suitable form.

There are actually eight distinct cases that must be considered for this minimum information plane. These consist of various relationships between A and B and the midpoint value M. These are shown as:

1) $A \geq B \geq M$
2) $B \geq A \geq M$

$B \geq M \geq A$

  3) $B \geq \bar{A} \geq M$
  4) $\bar{A} \geq B \geq M$

$A \geq M \geq B$

  5) $\bar{A} \leq B \leq M$
  6) $B \leq \bar{A} \leq M$

7) $M \geq A \geq B$
8) $M \geq B \geq A$

These relationships are graphically shown in Figure 35.

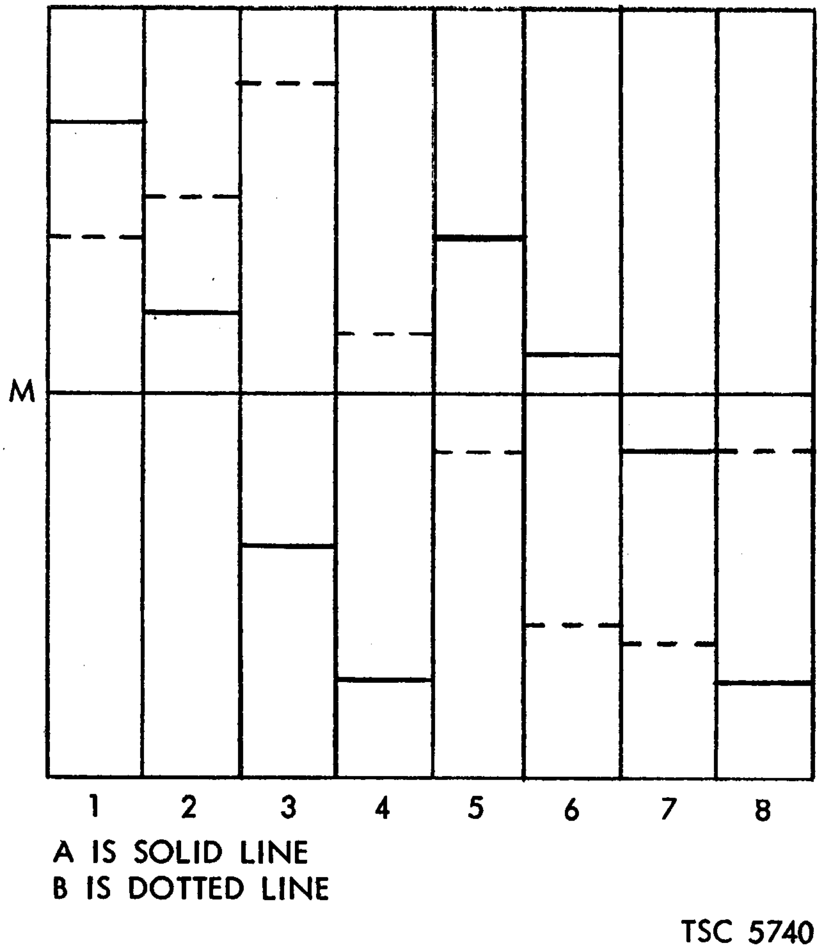


Figure 35. Relationships Between A and B

Synthesis of the required networks for R_1, R_2, and R_3 is accomplished by resorting to the fact that if the following three questions are answered, the input transducer states are uniquely described. These are

1. Is either $B > A$ or $\overline{B} > A$
2. Is $A > M$
3. Is $B > M$

The minimum information plane to describe two input variables and that answers the three questions above is shown in Figure 36. In Figure 37, a network capable of producing the outputs required in (2) above is shown. If B is substituted for A in Figure 37, then a network capable of producing the outputs required in (3) will be formed. Figure 38 shows the network capable of providing R_1 response.

By way of a simple example, Teledyne has illustrated several very useful data handling concepts. The networks discussed can all be fabricated from one device, namely, the non-numeric data handling element, which is based upon the operation of the biological neuron. A two variable stimulus was used for the example. The system described will be able to recognize if the present stimulus is similar to a previous excitation. Once it is possible to identify the nature of a stimulus, it is a simple extension to store response patterns that correspond to the applied stimulus.

3.4.16 Non-Numeric Data Handling System

Attention is next turned toward application to a more complete system that would handle multi-variable inputs. This system would not only have

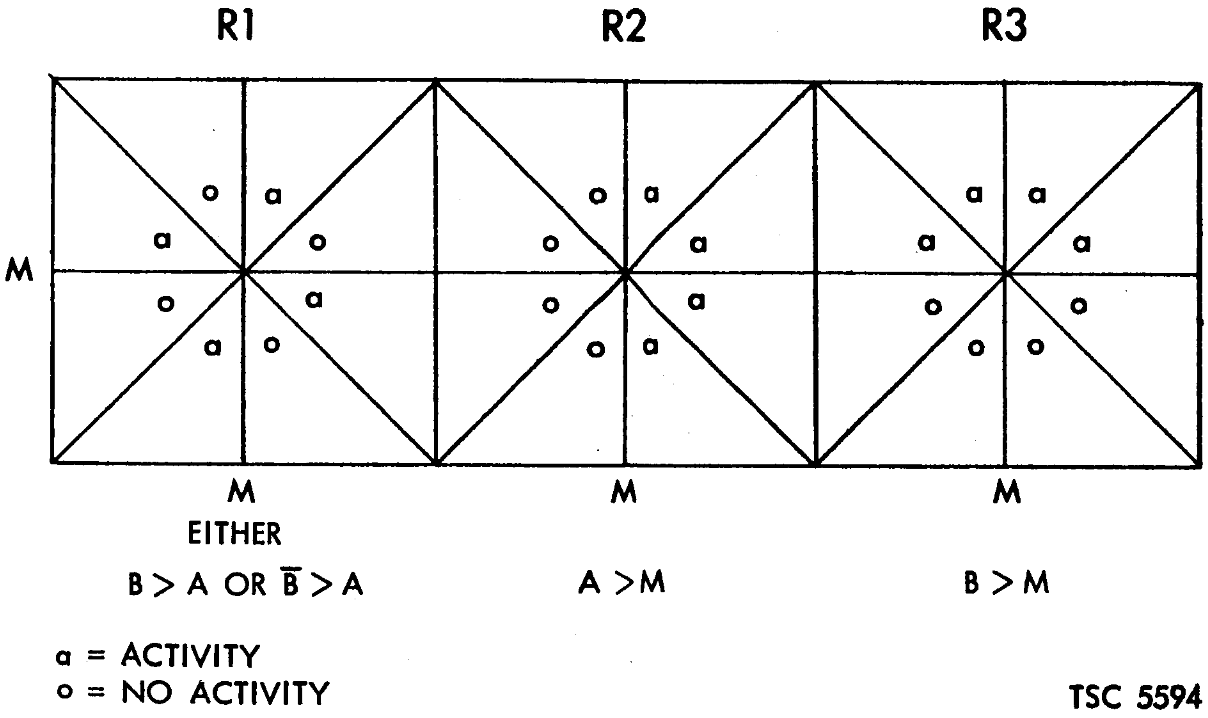
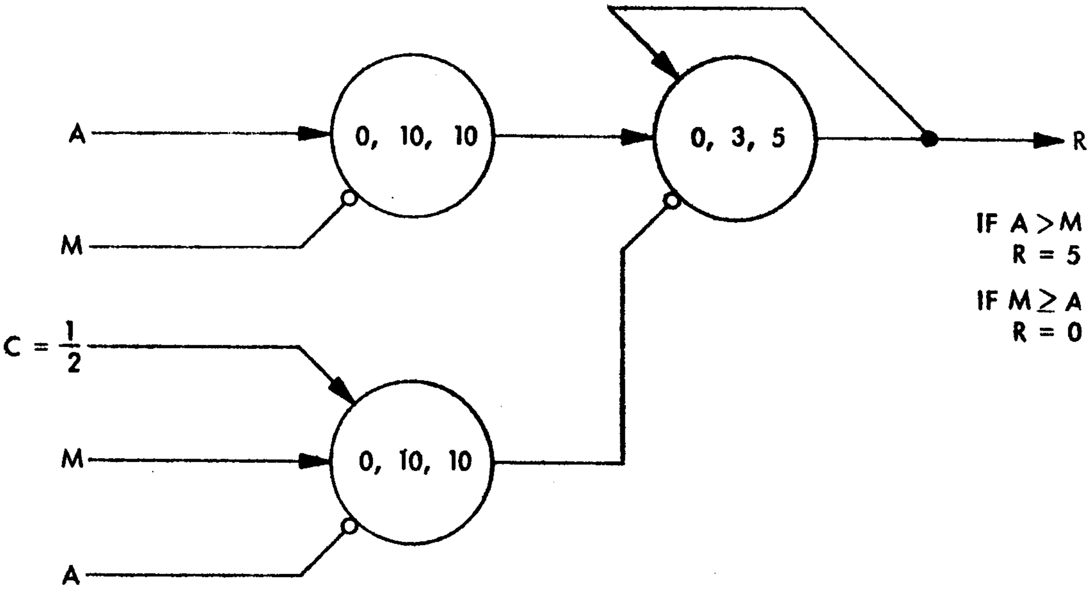
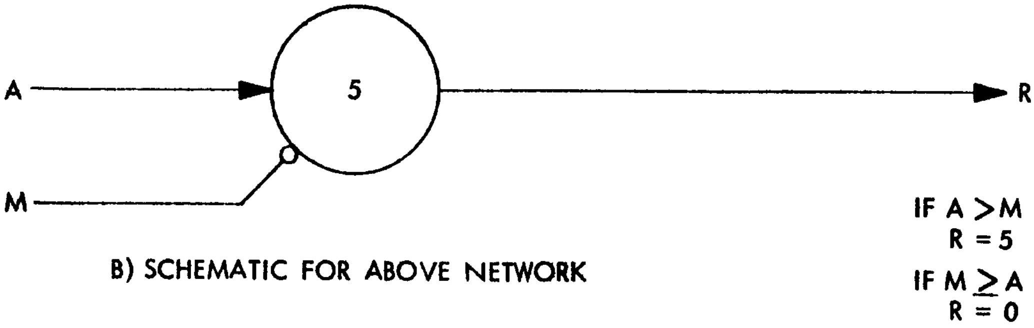


Figure 36. Minimum Information Plane to Describe Two Input Variables



A) ACTUAL NETWORK FOR GENERATING OUTPUT IF A > M



B) SCHEMATIC FOR ABOVE NETWORK

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Figure 37. Example of a Non-Linear, Non-Numeric Data Handling Element

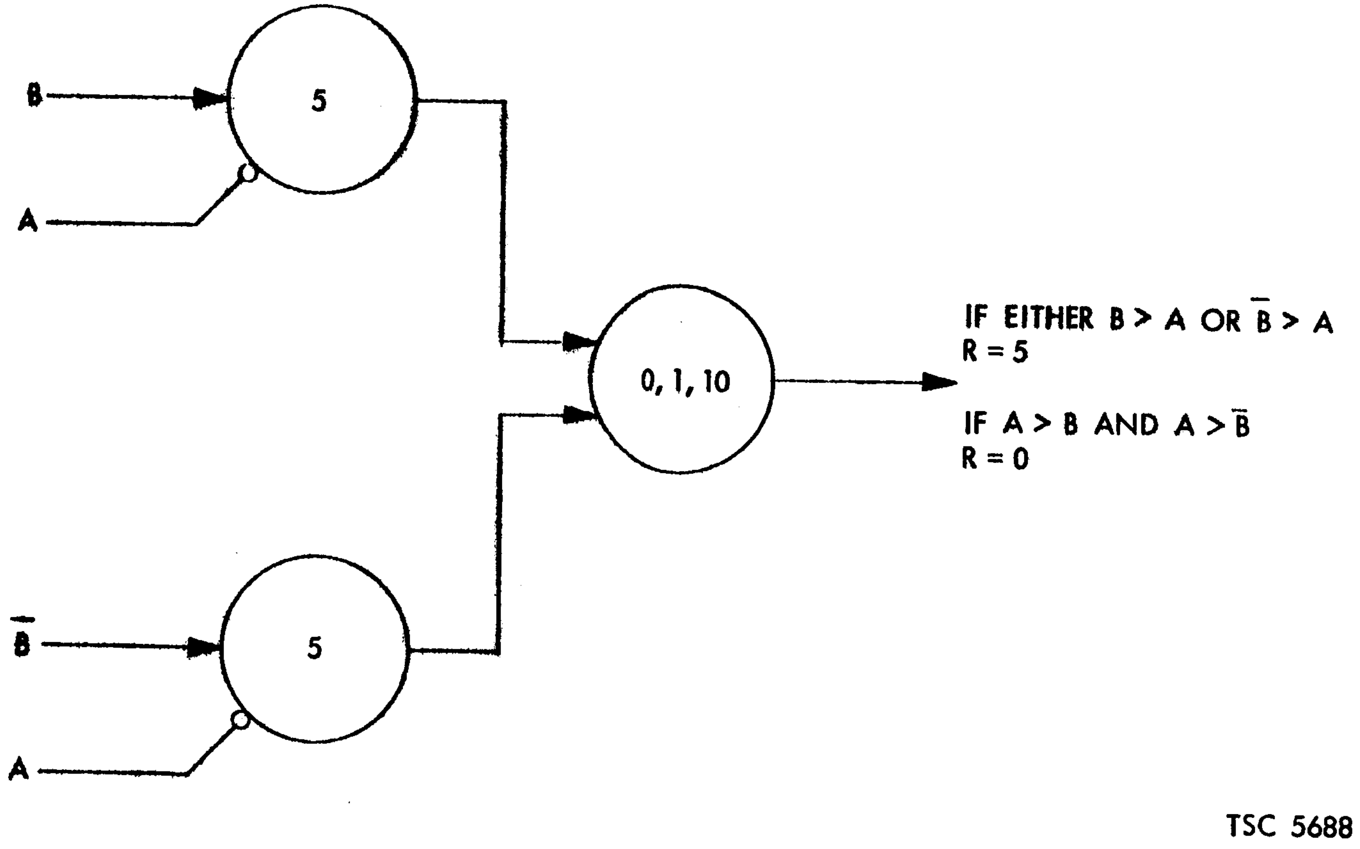

Figure 38. Network for Generation of R for (B or $\overline{B}$) > A the ability to examine stimulus patterns and be able to decide whether it had been previously exposed to similar patterns of stimuli, but the system would also be capable of operation in a second mode of operation. When a condition of low input data exists, the system can be switched to the second mode of operation. In this mode, stored patterns in the memory unit are extracted from the memory and are presented back to it as if they were fresh inputs at the same time the correlation level is lowered and all other patterns stored in the memory are tested against the one pattern extracted. Thus the non-numeric data handling system is capable in the true inductive sense of creating new plausible patterns by combination of two or more old patterns. In this sense, this system appears to have many of the properties of intelligence. In order that incorrect combinations of old patterns are not permitted, a censor network is utilized. This network checks for contradiction of a potential new pattern by total memory contents.

The use of the word contradiction in describing the action of the censor is really a consequence of the end result rather than a description of the process carried out. In reality, there is no such thing as a contradiction possible in this system, only a degree of correlation of new patterns with patterns that have previously been stored. The censor correlates new patterns with the stored patterns at a lower level of correlation than that used for stimuli generated by operation in the second mode discussed above. The object of this process is to determine the degree by which the new pattern agrees in part with large numbers of previously-stored patterns. If the average level of activity is high, then two things happen. First, the new pattern slightly modifies the existing memory pattern, and secondly, an output of the censor is fed back to the correlator to decrease the acceptable level of correlation. This modified memory pattern is then correlated with future inputs. If on the other hand, the censor produces little or no output, then the level of required correlation is increased to a limiting condition where no correlation is found and the incoming signal is treated as a new pattern. The end result of this process is the combining of new and old patterns for which there exists a stored history of credibility by virtue of machine experience and the skeptical acceptance of information which is unlike anything that has been previously stored. A block diagram of this entire system is shown in Figure 39.

In addition to providing external input patterns to the system, a second set of inputs must be provided. These inputs are associated with patterns originating within the system itself. For example, if a group of output devices are provided, a set of information patterns are developed representing the internal state of these outputs. Also contained in this special group of inputs are other less obvious patterns all associated with the internal functioning of the system. It is extremely important that the system be capable of evaluating the effect of a changing environment upon itself.

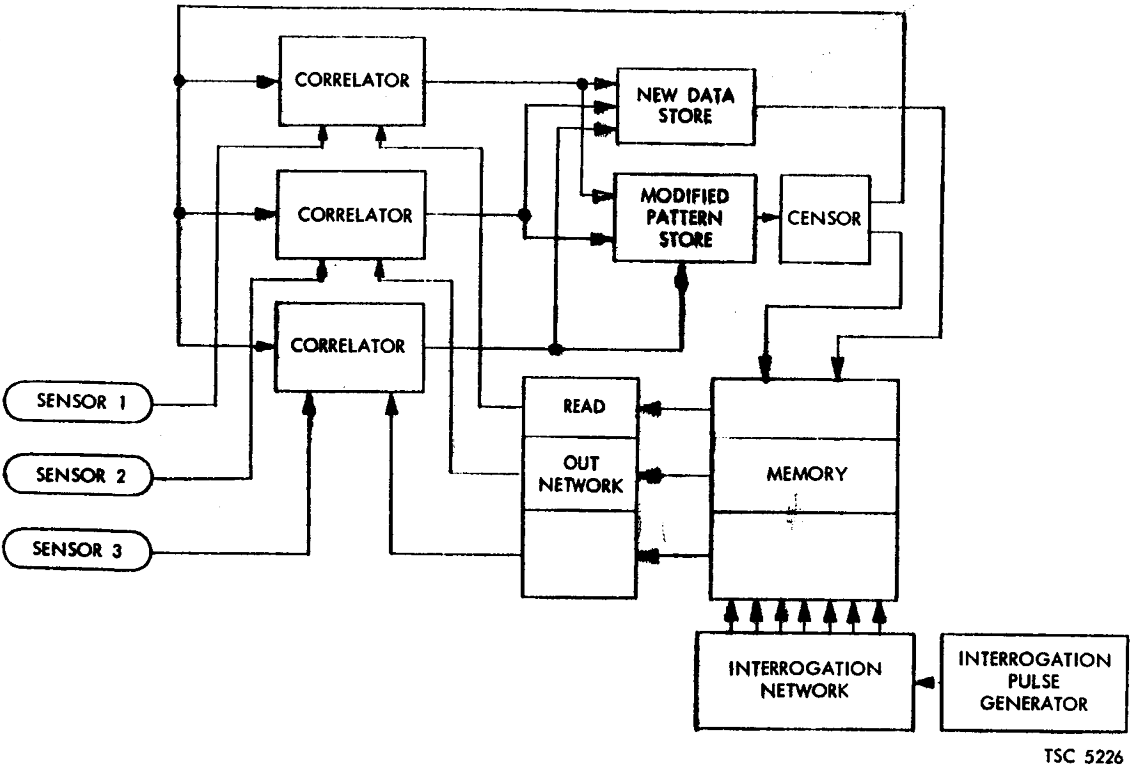

Figure 39. Input and Memory Portion of a Non-Numeric Data Handling System

4.0 OUTPUT SUBSYSTEM

4.1 INTRODUCTION

The output subsystem of man that Teledyne has chosen to investigate is the musculo-skeletal subsystem. This is the subsystem that gives man the ability to produce his bodily motions. These motions are produced by means of the contraction of a muscle that directly or indirectly originates or inserts from a part of the skeleton.

Movements of the skeleton are accomplished by means of non-rotary mechanisms, such as antagonistic and synergistic muscle combinations. By these means, the skeleton has evolved within one envelope, and thus has overcome the problem of utilizing seals to keep lubricants within joints and prevent atmospheric contaminants from affecting the operation of movable connections. Many mechanical devices have been designed that require the use of seals. Two of these devices that are similar to the respiratory subsystem of man are the compressor and the vacuum pump. These machines require seals that are rather difficult to design and fabricate. Vacuum technology has not yet devised a seal that is completely satisfactory to enable a rotary motion to be transmitted from the environment external to the vacuum chamber through a seal into a low pressure enclosure. One of the seals that has been found to be useful is the bellows seals, but, as Figure 40 indicates, this is quite a complex mechanical assembly that is not simple to fabricate.

Today, devices are designed that must successfully function in the vacuum of space. It has been found that joints of the traditional rotary type are for the most part unacceptable in space, because of the difficulties of constructing a seal that will remain airtight. Rotary seals allow the lubricant to escape into space, which brings about freezing of the joint. External joints for the Lunar Excursion Module might well be constructed in a fashion very similar to that of the human body in order to avoid the leakage of lubricant.

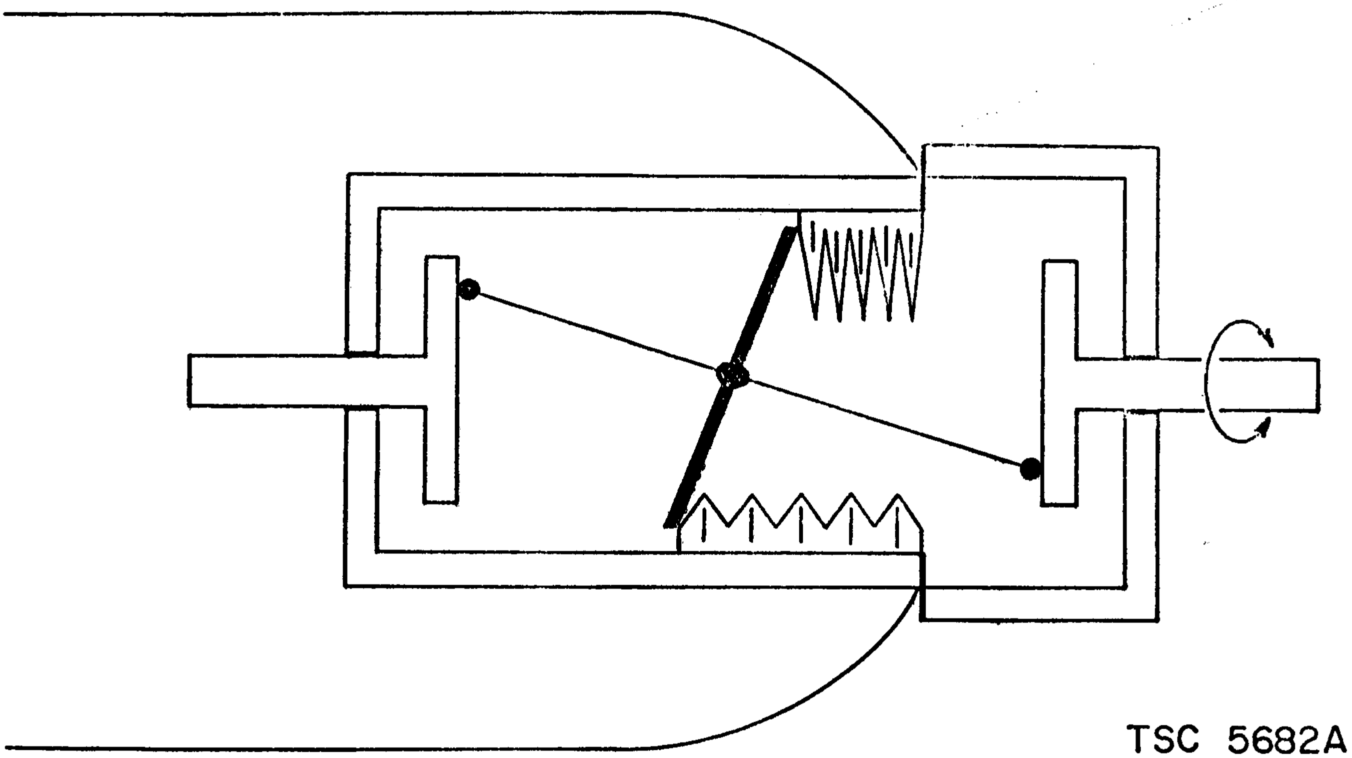

Figure 40. Bellows Seal

Investigation of the human musculo-skeletal subsystem is undertaken because this subsystem has overcome the serious mechanical problem of providing joints that are sealed to the environment. A study of the biomechanisms of human motion is made in an effort to describe the actions of selected bodily parts and to examine the joint articulations.

To begin Teledyne's study of the biomechanisms of human motion, an examination of bone tissue is made. The composition of bone tissue is discussed and the four classes of bone structure are described. Next, the two major types of joints are presented. Examples of each of the various classifications of specific joints within the major types are also given. Specific motions produced by the muscles, such as, abduction and adduction, are described and illustrated. Following this description, an examination of the moduli of elasticity of the various anatomical parts that compose the joints is conducted. The strengths of bone tissue and cartilage are reviewed, and the breaking point in compression and in bending for selected bones is given. Smooth, striated, and cardiac muscle are next described, and the bandage like fascia, which binds striated muscle tissue together, is viewed with respect toward its ultimate and safety stresses as well as its elasticity.

In making a detailed study of the shoulder joint, a number of parallels with mechanical junctions become apparent. The shoulder moves by means of a ball-and-socket joint, which has been used in the design of many machines. Angular movement of the humerus in its socket is examined and the geometry of the joint is explained. The capsule that envelopes the joint is described and illustrated. Though the capsule structure places limits on the motion of the shoulder, the allowable movements of the clavicle and scapula permit the humerus to travel through a wide range of motion. A listing of the muscle power of each of the six basic groups of muscles in the shoulder-arm complex is also given.

Continuing the examination of the joints of the body the forearm and hip are next studied. In the forearm, the principle movement is flexion with an average range for this movement of about 141 degrees. A second ball-and-socket joint of the body is in the hip. This joint does not permit as much motion as the shoulder joint. One of the reasons is that the hip joint must support a good deal more weight than the shoulder. As in the shoulder joint, the hip joint has a surrounding capsule and a number of ligaments to support and retain the head of the femur in the acetabulum.

Examination of the joints of the body will suggest many mechanical innovations that can be introduced into future machine design. Biological articulations are highly efficient in carrying out desired movements. Mechanical designers will find a wealth of possible machine improvements by a close examination of the biomechanisms of the human body.

4.2 BIOMECHANISMS OF HUMAN MOTION

4.2.1 Bone Tissue

Indeed, the musculo-skeletal system of man has a number of advantageous aspects that are worthy of study. To begin this study, an examination of bone tissue will be made. Bone tissue is composed of osteocytes (bone cells) that form either an outer, dense material (compact bone) or an innter, spongy, more porous material (cancellous bone). Osteocytes form a large number of rather uneven bone structures. The four main classes of bone structures are the following: long, short, flat, and irregular. Long bones, only found in the extremities, consist of a shaft or body, two end portions, a medullary cavity extending within the shaft and containing yellow bone marrow, compact bones, and spongy bone. Short bones, such as those of the wrist and ankle, consist of a heavy shaft of spongy, elastic material within a thin outside layer of compact bone. The flat bones, such as the ribs and sternum, consist of spongy material between two platelike coverings of compact bone. Flat bones protect internal organs and provide surfaces for the attachment of muscles. Irregular bone-like vertebrae are similar to the short bones in structure and contain red bone marrow.[1]

4.2.2 Types of Joints

Bones in the body are joined by two major types of joints, diarthrodial (a joint in which there is an articular cavity) and synarthrodial (a joint that does not have an articular cavity). A typical diarthrodial joint is shown in Figure 41 . This figure indicates that the joint is encased in a sleevelike ligamentous capsule that is lined with synovial

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[1] Franz Frohse, Max Brödel, and Leon Schlossberg, Atlas of Human Anatomy, 1959, p. 21.

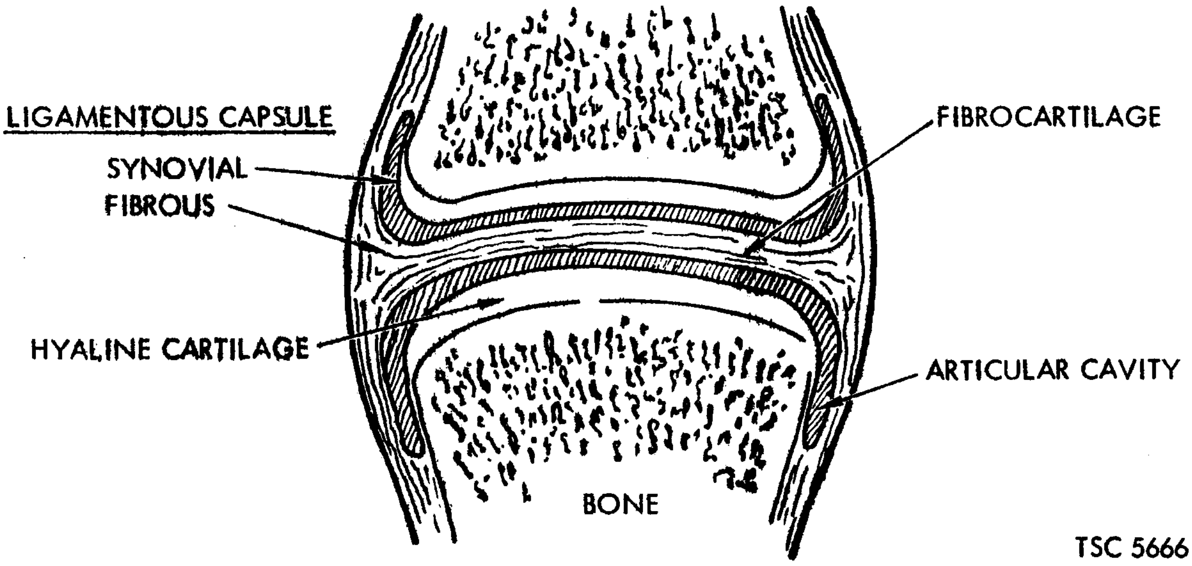

Figure 41. Diathrodial Joint

membrane, which secretes synovial fluid for lubricating the joint. The articular surfaces are smooth and covered with cartilage, usually hyaline, but occasionally fibrocartilage.[1]

There are six classifications of diarthrodial joints: irregular, hinge, pivot, ovoid, saddle, and ball-and-socket.

Irregular - Joint surfaces are irregularly shaped and only permit gliding movement. Example: The carpal joints.

Hinge - One surface is spool-like, while the other is concave. Motion is like a hinge in that the concave surface fits over the spool-like process and glides partially around it. Example: elbow joint.

Pivot - The joint is peglike or there may be two long bones fitting against each other near each end in such a way that one bone can roll around the other one. In the latter type, a small concave notch on one bone fits against the rounded surface of the other. Rotation is the only movement permitted in either kind of pivot joint. Example of peglike joint is the connection between the atlas and axis. Example of second type of pivot is the radioulnar joint.

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1. Katharine F. Wells, Kinesiology, 1960, p. 13

Ovoid - This joint is composed of an oval convex surface that fits into a reciprocally shaped concave surface. Movement can occur in two planes, forward and backward, and from side to side. Example: wrist joint.

Saddle - The two ends of the convex surface are tipped up making the surface concave in the other direction like a western saddle. Fitting over this is a reciprocally concave-convex surface. The difference between the ovoid and the saddle joint is that the latter has greater freedom of motion. Example: carpometacarpal joint of thumb.

Ball-and-socket - This joint permits the spherical head of one bone to fit into the cup or saucerlike cavity of the other bone. It is a triaxial joint, since it allows movement about three axes.

Summary of diarthrodial joints:

Number of Axes	0	1	2	3
	Non-Axial	Uniaxial	Biaxial	Triaxial
Classification	Irregular	Hinge	Ovoid	Ball-and-Socket
		Pivot	Saddle	

Synarthrodial joints are formed by cartilage, fibrous tissue, or ligament. The three types of joints are the following: cartilaginous, fibrous, and ligamentous.

Cartilaginous - Joints united by fibrocartilage permit bending and twisting motion, while those united by hyaline cartilage only allow slight compression. The epiphysial unions are jointed by hyaline cartilage, and the articulations between the bodies of the vertebrae are formed of fibrocartilage.

Fibrous (Suture) - The edges of bones in the skull are united by means of a thin layer of fibrous tissue which is continuous with the periosteum. Sutures do not permit any movement.

Ligamentous (Syndemosis) - Ligaments tie together bones that are either adjacent or quite widely separated. These ligaments may be in the form of cords, bands or flat sheets. Movements that are allowed are limited and of no specific type. A ligamentous joint provides the midunion of the radius and ulna.

4.2.3 Specific Motions Produced by Muscles

Each of the joints that have just been described only allow specific types of motion. In the jargon of kinesiology (the science of human motion) these specific motions have been given names. The kinesiologic terms are a precise and brief way to refer to such motions and thus will be frequently used in this report. The following listing gives these terms and their meanings.

Abduction - movement away from the midline of the body, i.e., moving the legs away from each other. Figure 42 shows the average limits of motion of hip abduction for a group of 24 individuals that range in age from 17 to 20.

Adduction - movement toward the midline of the body. The shoulder, hip, and wrist joints can be adducted.

Extension - a movement that increases the angle at the joint.

Flexion - a movement that decreases the angle at the joint. Flexion can be used to describe a motion of the joints of the shoulder, hip, elbow, knee, wrist, and ankle. Figure 43 shows hip flexion with the knee straight. Motion of the elbow begins with the forearm perpendicular to the arm or at a right angle. To decrease that angle is to flex and to increase the angle is to extend the moving segment.[1]

Pronation - inward rotation of the forearm.

Rotation - rotary movement of a segment about its own longitudinal axis.

Outward rotation - the anterior aspect turns laterally

Inward rotation - the anterior aspect turns medially

Supination - outward rotation of the forearm.

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1. M. L. Moore, "The Measurement of Joint Motion, Part I," <u>Physical Therapy Review,</u> Volume 29, 1949, p. 200.

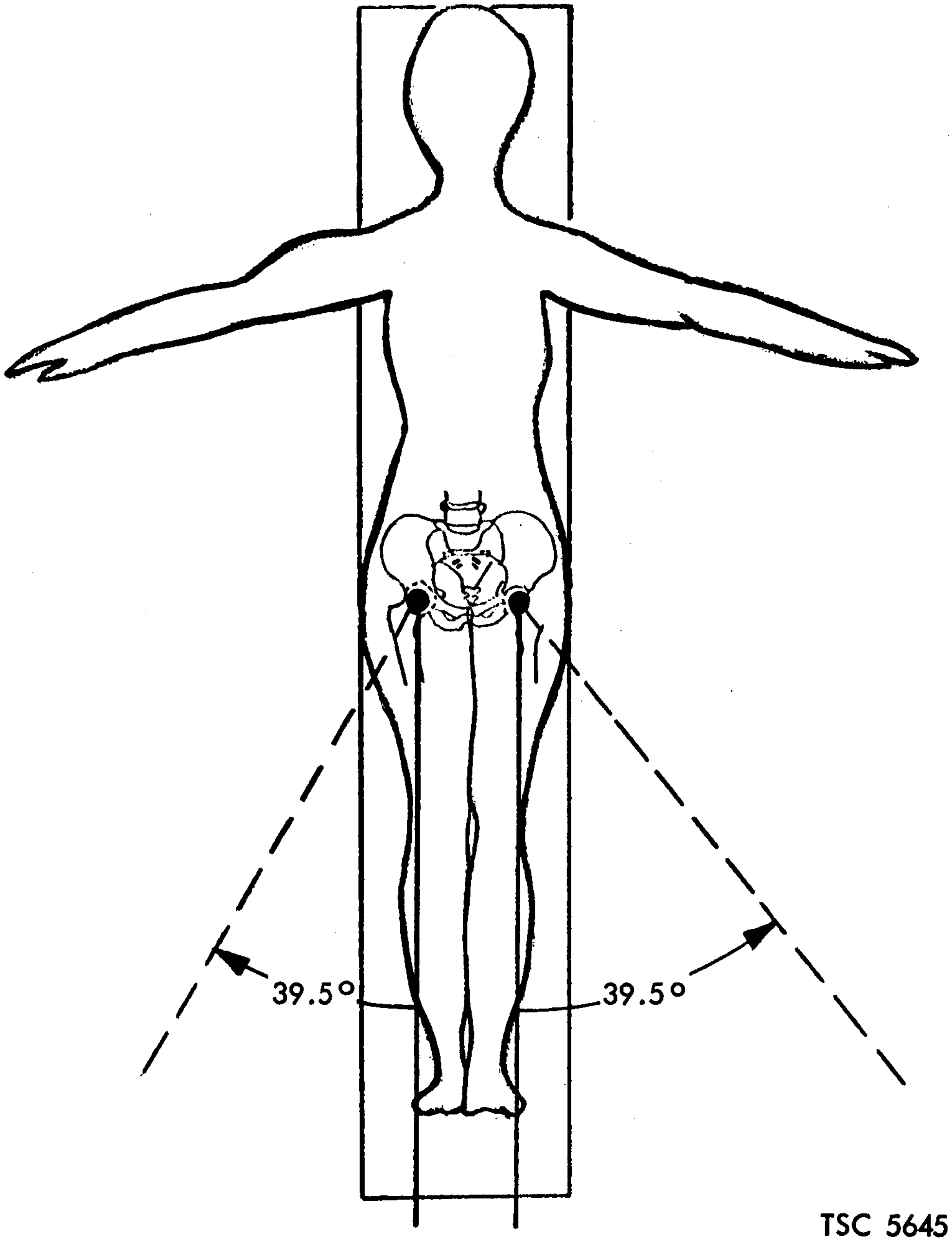

Figure 47.

Hip Abduction

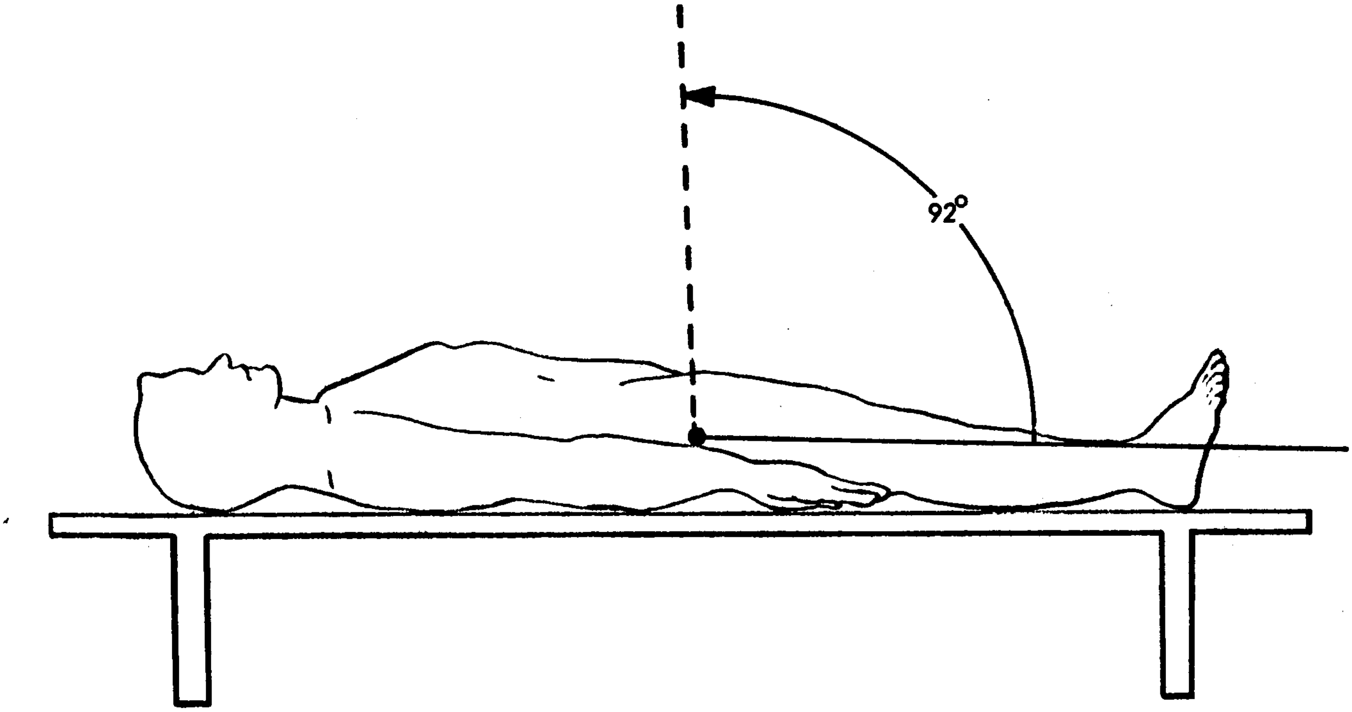

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Figure 43.

Hip Flexion with Straight Knee

4.2.4 Bone Strength

An examination of the moduli of elasticity of the various anatomical parts that compose diarthrodial and synarthrodial joints will be helpful in understanding the forces exerted on and by each member of the joint. To begin this discussion, it would be appropriate to define Young's modulus of elasticity. The measure represents the theoretical force per unit cross section that will elongate a body by its own length, i.e, double the original length of the body. Of course, many bodies will break long before the modulus of elasticity is reached.

Bone is an example of a very inelastic structure that has a tensile modulus of elasticity of 2000 kg per square mm and a breaking point of only 10 kg per square mm. This means that the elongation up to the breaking point is only one-two-hundredth of the length of the rod. Now as a comparison, consider steel with a modulus of elasticity of 29,000,000 pounds per square inch (2030 kg per square mm). The yield point is 40,000 pounds per square inch (28 kg per square mm), while the ultimate tensile strength (breaking point) is 72,000 pounds per square inch (51 kg per square mm).[1] Thus the elongation up to the breaking point is one-fortieth of the length of the rod, or steel is about five times more elastic than bone.

The compressive resistance of bone is between 12.56 and 16.85 kg per square mm. Testing conducted some years ago by Messerer of various bones in compression has produced the following data:

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[1] Charles D. Hodgman, Editor, Handbook of Chemistry and Physics, Thirty-Eighth Edition, 1956, p. 2001.

Bone	Breaking Point (kg)
Humerus	600
Femur	765
Patella	192
Tibia	450

These values are all above the usual fracture producing forces, but fractures are seldom due to compression alone. Usually there is a combination with bending and shearing stresses. Experimental work by Steindler in applying bending forces to four bones to find their breaking points has yielded the following data:

Bone	Breaking Point (inch pounds)
Humerus	885 - 1500
Radius	391
Ulna	340
Fibula	216

The modulus of elasticity of cartilage is 0. 9 kg per square mm, and the tensional resistance is 0. 17 kg per square mm. Cartilage can withstand 1. 57 kg per square mm in compression, but only a shearing resistance of 0. 35 kg per square mm. Torsional resistance is 0. 24 kg per square mm.[1]

4. 2. 5 Types of Muscles

All of the movements of the parts of the body are produced by muscles. There are three types of muscle that differ in structure and physiologic characteristics. The three types of muscles are the following: smooth, striated, and cardiac.

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[1] Arthur Steindler, Kinesiology of the Human Body, 1955, p. 40.

Since smooth muscle cells are elongated and thin, they are called muscle fibers. A portion of the cytoplasm of each fiber is composed of fine fibrils or myofibrils that run the length of the cell. The myofibrils are believed to represent the contractile elements of the cell. Muscle cells account for most of the elasticity of muscle since the tendons are made of inelastic collagenous fibers.

Smooth muscle is found in the walls of hollow organs such as the stomach, intestine, uterus, and blood vessels. Contraction is slow and frequently rhythmic. This type of muscle can produce a constant tension and length over long periods and thus can maintain the same pressure within an organ.[1]

Striated muscle forms the muscles that are attached directly or indirectly to the bones of the skeleton. Contractions of this muscle are rapid and powerful, but there are no rhythmic actions although a slight tension (tonus) is normally maintained. As in smooth muscle, a large part of the cytoplasm consists of myofibrils running the length of the cell. Segments of adjacent fibrils are lined up in such a way as to give the appearance of bands running across the cell. This characteristic gives the tissue its name, striated muscle. Cardiac muscle is only found in the region of the heart and is similar in some respects to both smooth and striated muscle.

A muscle may be described as a bundle of contractile fibers held together by a sheath of connective tissue. It is attached to bone by means of tendons or aponeuroses (fibrous sheets) which stem from the connective tissue sheath.

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1. Clyde Marshall, Edgar L. Lazier, An Introduction to Human Anatomy, 1955, p. 70.

The two most important characteristics of muscle tissue are extensibility and elasticity. The tissue can contract beyond its normal resting length by pulling from both ends in toward the center. This is a chemical process that shortens the muscle and increases its circumference. Experimental evidence indicates that muscle tissue can shorten to about one-half of its resting length and can be stretched to about 1.6 times its resting length.[1]

The amount of tension that will stretch a maximally contracted muscle to its original length is called the absolute muscle power. For one square cm of physiological cross section, the absolute muscle power is 5000-6000 pounds per square inch, while the safety stress is only about 2000 pounds per square inch. Thus a small tendon with a cross section of 0.01 square inch can only safely withstand approximately a 20 pound stress.

Closely associated with the musculature is the deep fascia, which is a type of fibrous connective tissue that forms both the enveloping sheaths for the muscles, nerves, and blood vessels and the partions that separate muscles and muscle groups from each other. Fascia thus binds muscle tissue together like a bandage.

The ultimate strength of fascia is approximately 7000 pounds per square inch, and the safety stress is 2000 pounds per square inch. Fascia is very elastic and can stretch an additional 91 percent over its normal length. The duration of the stress,though,can affect the tissue. Prolonged stress can result in a permanent elongation.[2]

4.2.6 The Shoulder Joint

Now that the classes of bone structure, types of joints, classification of the movements of the bodily parts, strengths of bone and cartilage,

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[1] Wells, op. cit., p. 21.

[2] Steindler, op. cit., p. 55.

and kinds of muscles and their associated parts have been discussed, we are in a position to examine the static and dynamic characteristics of one of the most interesting joints of the body. This joint permits motion along three axes and allows the greatest motion of any joint in the body. Unlike the mechanical joints used in many machines, this joint is sealed and can operate in the air or under water with equal ease. Since the joint is sealed, problems with unwanted particles entering from the atmosphere as well as the escape of lubricant do not plague its operation. This joint merits study because is has proven to be a high successful anatomical connection and an asset to those animals that have this joint.

The connection that will be examined is the ball-and-socket joint of the shoulder. This connection is composed of the shoulder blade, clavicle, and shoulder joint that form a mechanical unit called the shoulder-arm complex (Figure 44). Only the rather weak sternoclavicular joint connects the shoulder complex to the skeletal trunk. The shoulder joint is formed by the articulation of the head of the humerus with the small, shallow, and concave glenoid fossa of the scapula. There is a considerable separation between the glenoid fossa and the humerus. Typical distances of separation are of the order of one to two inches.

The lack of congruity between the ball-shaped head of the humerus and the shallow concave glenoid fossa is perhaps the most striking feature of the scapulohumeral joint. There are more than 150 degrees of circular surface on the humerus, while the glenoid fossa of the scapula, which is more shallow and therefore has a larger radius, has only about 75 degrees of surface.[1]

For an adult, the center of the head of the humerus is about 2.5 cm from the periphery (Figure 45). There is a slight difference in the curving of the head in the sense that the radii become shorter from

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[1] Steindler, op. cit., p. 453.

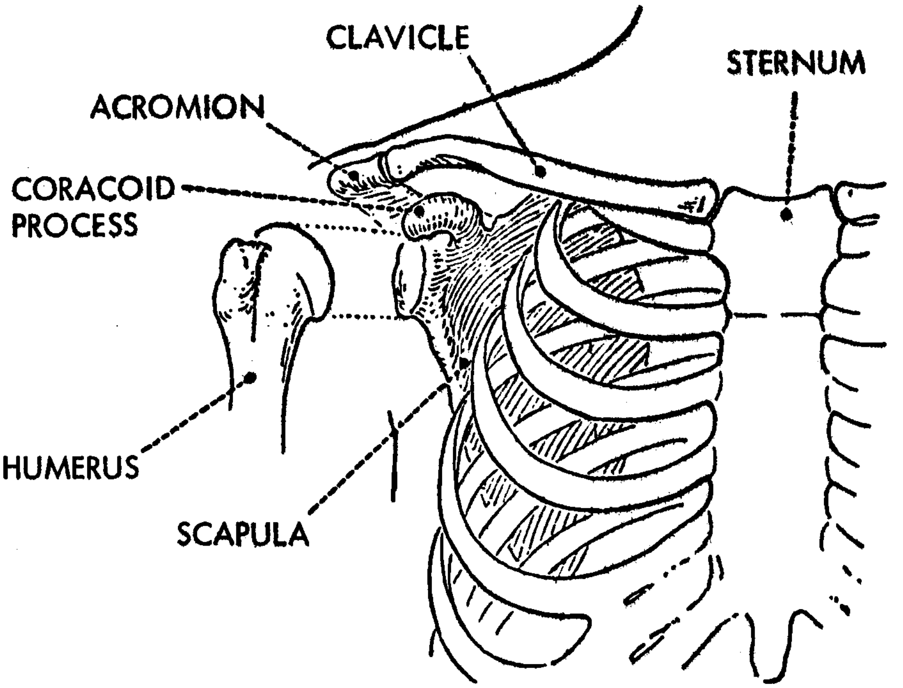

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Figure 44. Anterior View of Shoulder Joint

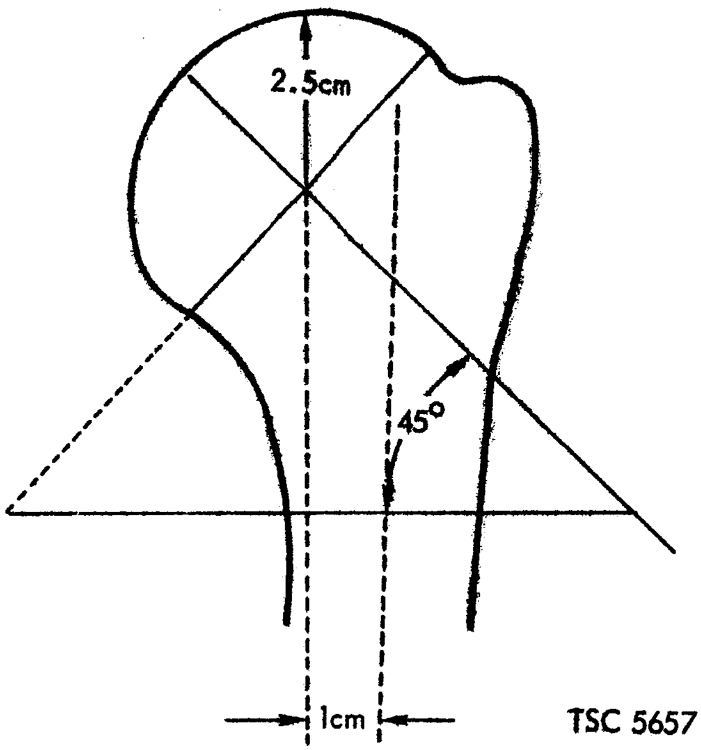

Figure 45. Head of Humerus

laterally to medially, but for all practical purposes the head can be considered as a half-sphere. The neck and head of the humerus are angulated against the shaft from 45-50 degrees in the frontal plane.

A radius of curvature of 24 - 26 mm is typical for the glenoid fossa of an adult. Its greatest diameter is 2. 5 - 4 cm in the frontal plane, while the head of the humerus may have a diameter from 6. 5 - 7 cm. In the sagittal plane, the diameter of the glenoid is 2. 5 - 3 cm and its angular value is only about 50 degrees. The contact area of the head with the glenoid is small and occupies only a portion of the lower medial quadrant of the head and of the corresponding area of the glenoid. With the labrum, the joint surface of the glenoid is substantially increased.

A capsule completely envelopes the joints. The capsule is sleeve-like and attaches proximally to the circumference of the glenoid cavity (Figure 46) and distally to the anatomic neck of the humerus. Both ligaments and muscle tendons reinforce and support the capsule. There are three glenohumeral ligaments that are adjacent and strengthen the inner fibers of the front and lower part of the capsule. These ligaments attach along the anterior edge of the glenoid fossa from the apex to the inferior rim. Then they pass in front of and beneath the shoulder joint, to attach to the anterior and inferior portions of the anatomic neck of the humerus.[1]

The capsular apparatus fills a considerable space in the cavity and leaves only a small portion of the glenoid in direct contact with the humeral head. Hyaline cartilage covers the head of the humerus as well as the glenoid fossa. The cartilage becomes thicker nearer to the center of the humeral head, while in the fossa it is thicker around the circumference. Another layer of white fibrocartilage also protects the glenoid cavity. This cartilage is called the glenoid labrum and is thicker at the rim of the cavity and both deepens the fossa and cushions against the

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[1] Wells, op. cit., p. 111.

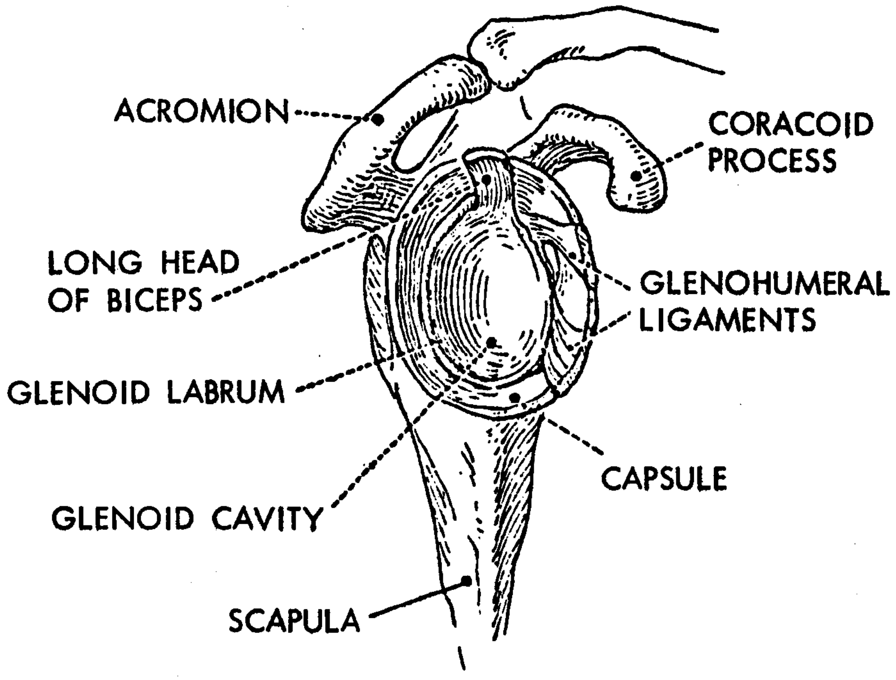

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Figure 46. Lateral View of Right Scapula

impact of the humeral head in forceful movements. Synovial membrane lines the capsule, folds back over the glenoid labrum, covers all but the upper portion of the anatomic neck of the humerus, and extends through the intertubercular groove in the form of a sheath for the tendon of the long head of the biceps.

Movements of the scapulohumeral joint successively tighten different portions of the capsule. In midposition,all portions of the capsule are equally relaxed. When the humerus is carried forward, the posterior portion of the capsule becomes tight, and when it is carried backward, the anterior tightens.

The entire arm is able to travel through a wide range of motion. Movements of the arm on the trunk do not take place at the shoulder joint alone, but they also involve movement of the shoulder girdle at the acromioclavicular and sternoclavicular joints. The clavicle rotates about the sternum, the scapula around the clavicle, and the humerus around the scapula which carries out rotational and translational movements against the thoracic wall. The freedom of the scapula augments the mobility of the shoulder-arm complex, but makes the problem of stabilizing it against the thorax more difficult. Most of the necessary stabilization comes from the powerful musculature that secures the shoulder girdle against the thorax.[1]

The movements of the shoulder blade are either translatory or rotatory. Translation of the scapula moves the bone up and down or forward and backward, while rotation is movement about a perpendicular axis near the upper outer or upper inner angle of the bone. Most motions are combinations of both the translatory and rotatory movements. Translatory movement of the scapula is largely controlled by muscles that pro-

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[1] Steindler, op. cit., p. 446.

vide motion in the frontal (up and down) and the horizontal (forward and back) planes. Rotary movements are either forward rotation of the lower angle or backward rotation of the lower angle.

A lateral movement of the lower angle of the scapula (rotation) occurs with the beginning of abduction. In abduction as in every movement of the shoulder-arm complex, there is cooperation between all of the joints of the shoulder girdle. Abduction causes the glenoid fossa to move to the most advantageous position for the head of the humerus. When the arm is raised sideways, the scapula rotates upward, making the glenoid fossa face somewhat upward (Figure 46). This figure indicates that the average abduction at the shoulder joint is 130 degrees. Figure 47 is a drawing that shows the approximate limit of horizontal extension-abduction at the shoulder joint. The limit is on the average about 44 degrees. Two other movements of the shoulder joint are shown in Figures 48 and 49. Figure 49 shows that the combined flexion-extension range is about 231 degrees, and Figure 50 indicates that inward and outward rotation of the shoulder joint permitsa total movement of 207 degrees.

To gain a familiarity with the working capacity of the shoulder girdle, a listing of the muscle power of each of the six basic groupings of muscles of the shoulder-arm complex is given below.[1]

Muscle	Power per cm^2 kgm
Inward rotators	5.374
Outward rotators	2.561
Forward flexors	4.375
Backward extensors	4.465
Adductors	4.320
Abductors	2.074

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[1] Steindler, op. cit., p. 466.

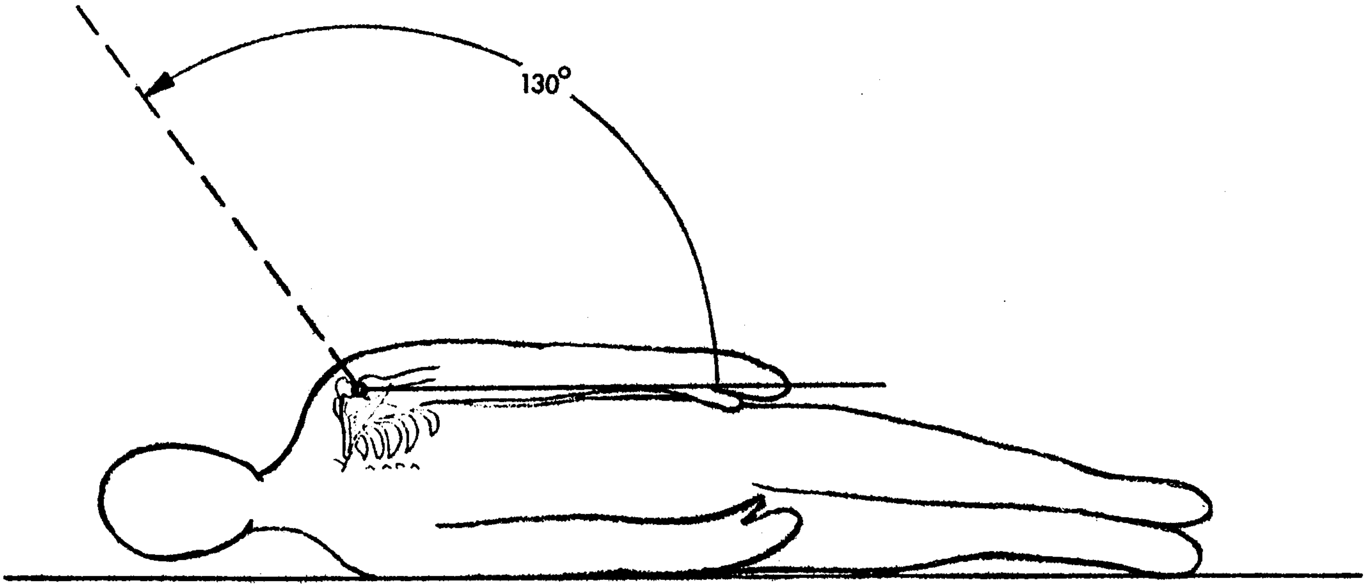

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Figure 47.

Abduction at the Shoulder Joint

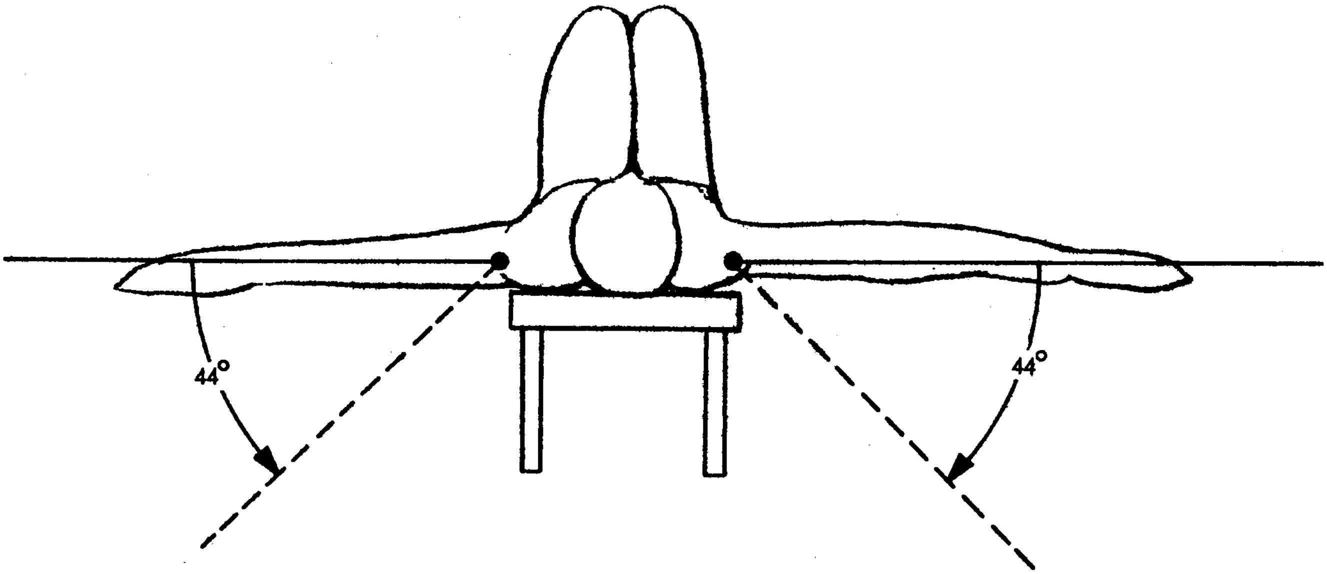

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Figure 48.

Horizontal Extension - Abduction at the Shoulder Joint

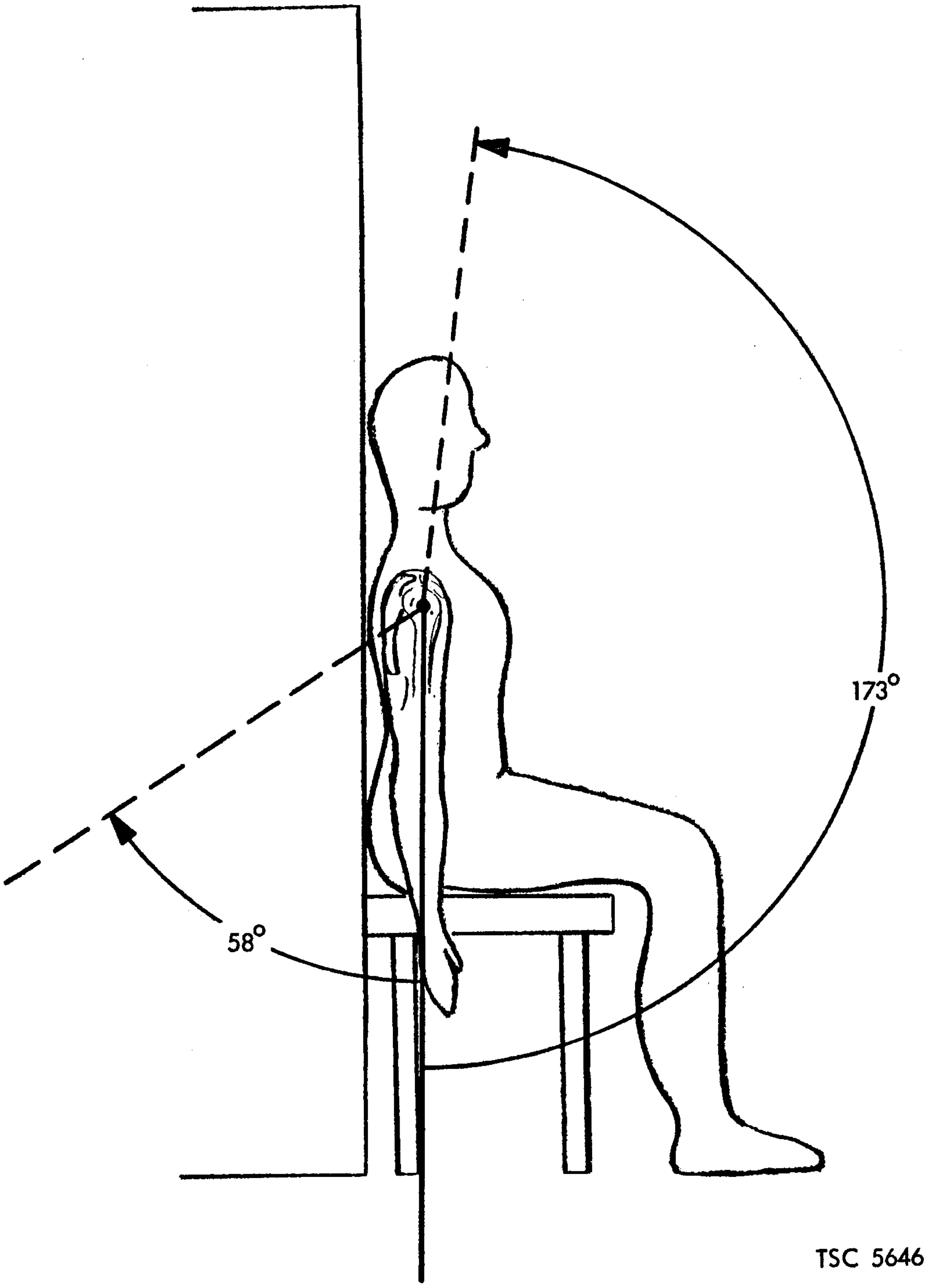

Figure 49.

Flexion and Extension at the Shoulder Joint

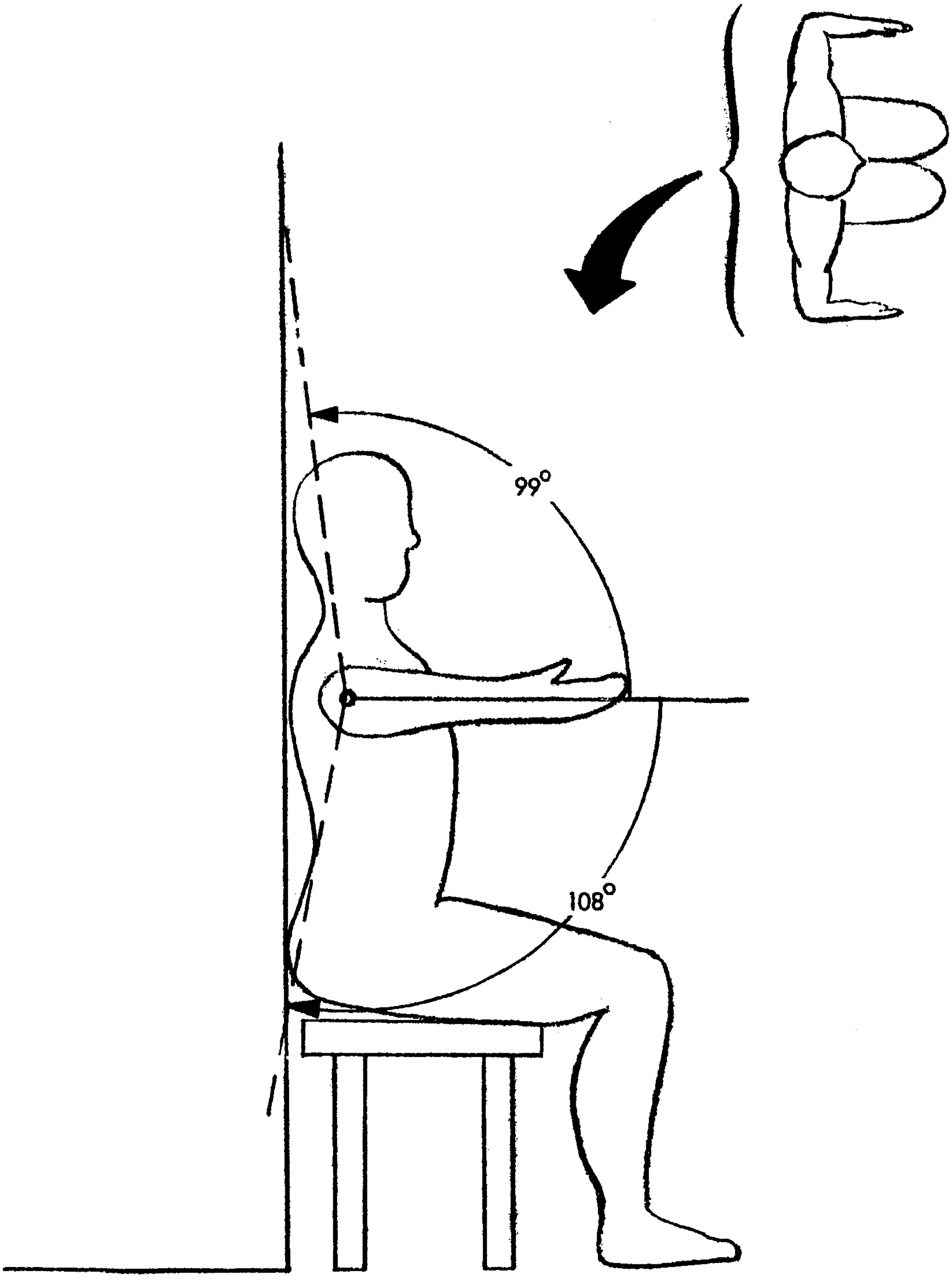

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Figure 50.

Inward and Outward Rotation at the Shoulder Joint

All of these six forces must be in equilibrium for the shoulder-arm complex to be at rest. When one or a combination of these groups of muscles increases its pull beyond the equilibrium condition, the arm begins to accelerate. Another set of muscles must soon act to slow the acceleration and complete the desired movement.

4.2.7 The Forearm Joint

In continuing the examination of the arm and moving in a distal direction, the forearm joint is encountered. The principle movement of this joint is flexion, and Figure 51 indicates that approximately 141 degrees is a typical value. The wrist allows flexion, extension, adduction, abduction as well as combinations such as flexion-abduction and extension-abduction to achieve any intermediate position. Figure 52 diagrams the flexion and extension ranges which are average values for the sample that was tested. In this case, the subjects were 10 men that were from 20 to 40 years of age. Using these same subjects, a test of abduction and adduction of the hand at the wrist was made. As Figure 53 indicates, the overall range of abduction and adduction is 95 degrees, which is considerably less than the range of flexion and extension.

4.2.8 The Hip Joint

There is another ball-and-socket joint in the body that should be examined. This is the hip joint (Figure 54). As Figure 54 shows, the acetabulum of the hip constrains the femur much more than the scapula constrains the head of the humerus. It should be realized, though, that the hip joint has much more weight to support than the scapulohumeral joint, and the acetabulum is helpful in this respect. There is a capsule around the hip joint as is shown in Figure 55. There are, of course, a number of ligaments that support and retain the head of the femur in the acetabulum. Figure 56 indicates how these ligaments attach to the head of the humerus and connect to the acetabulum.

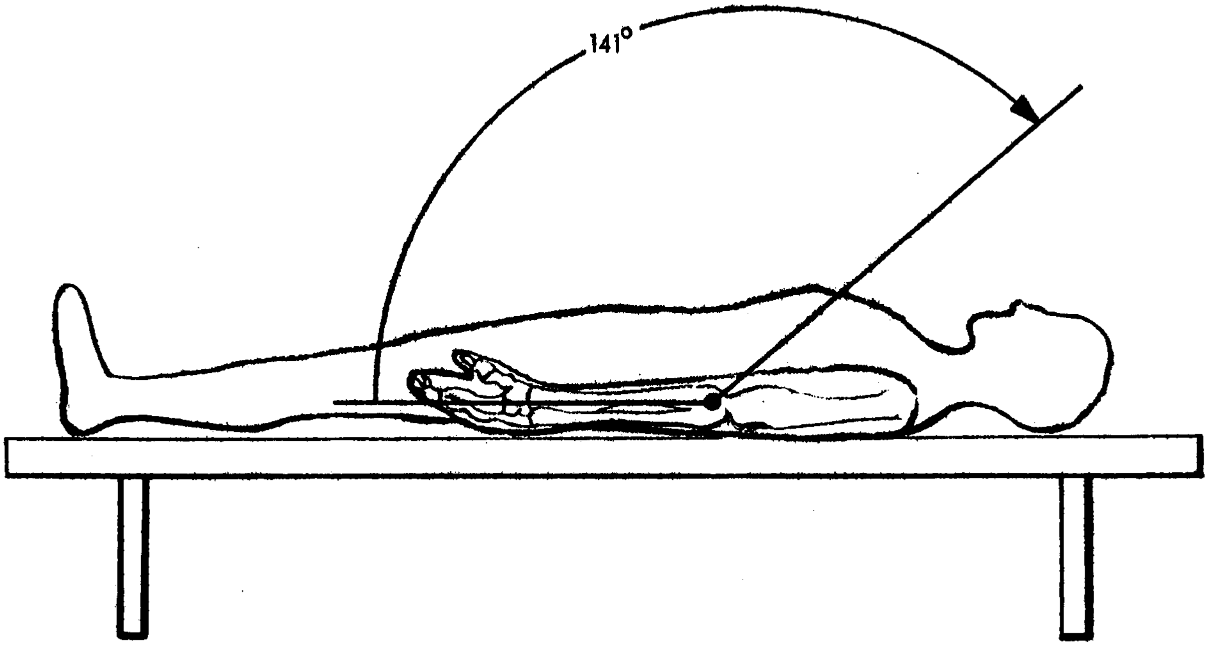

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Figure 51.

Flexion of the Forearm Joint

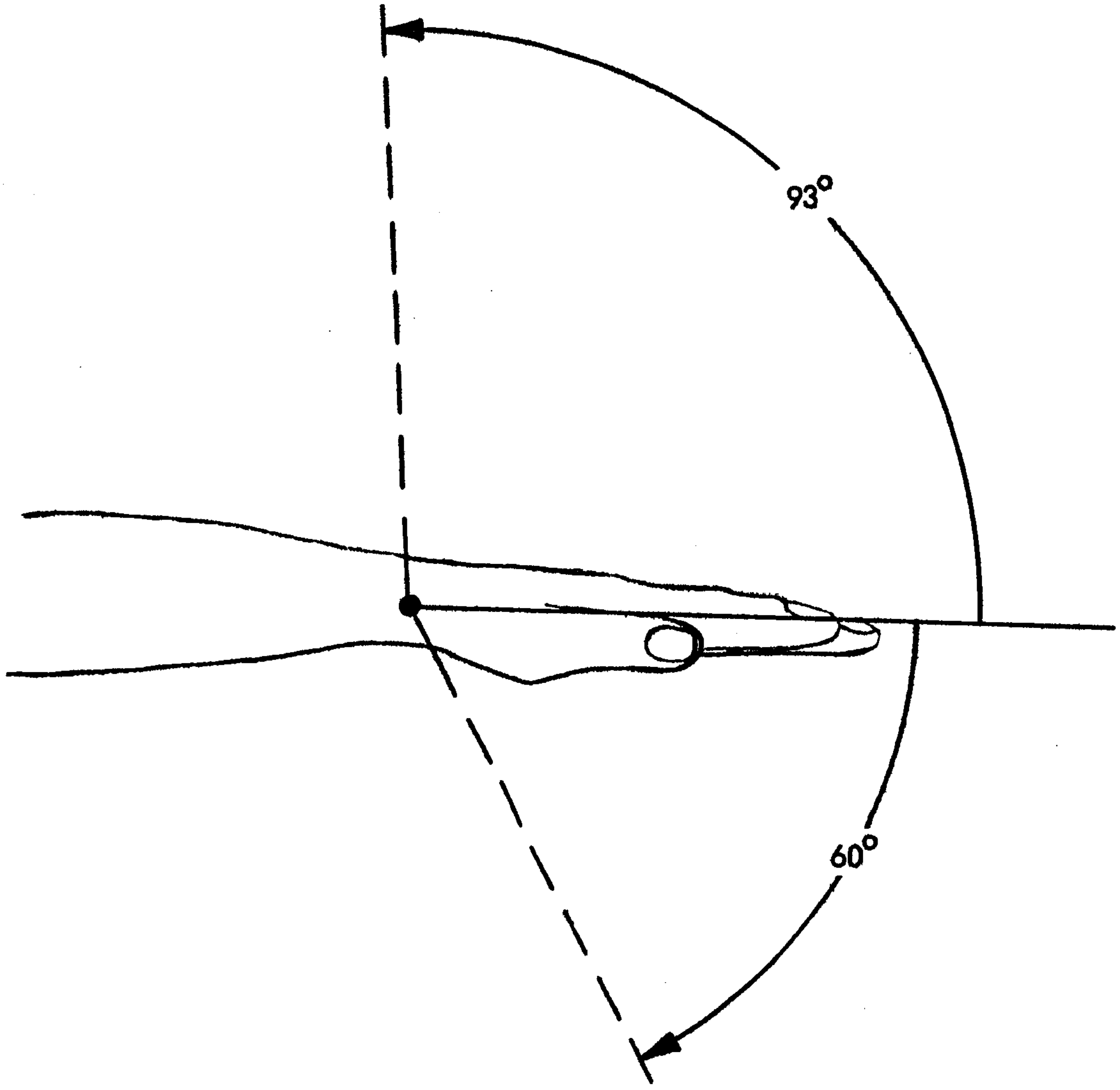

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Figure 52.

Flexion and Extension of Hand at the Wrist

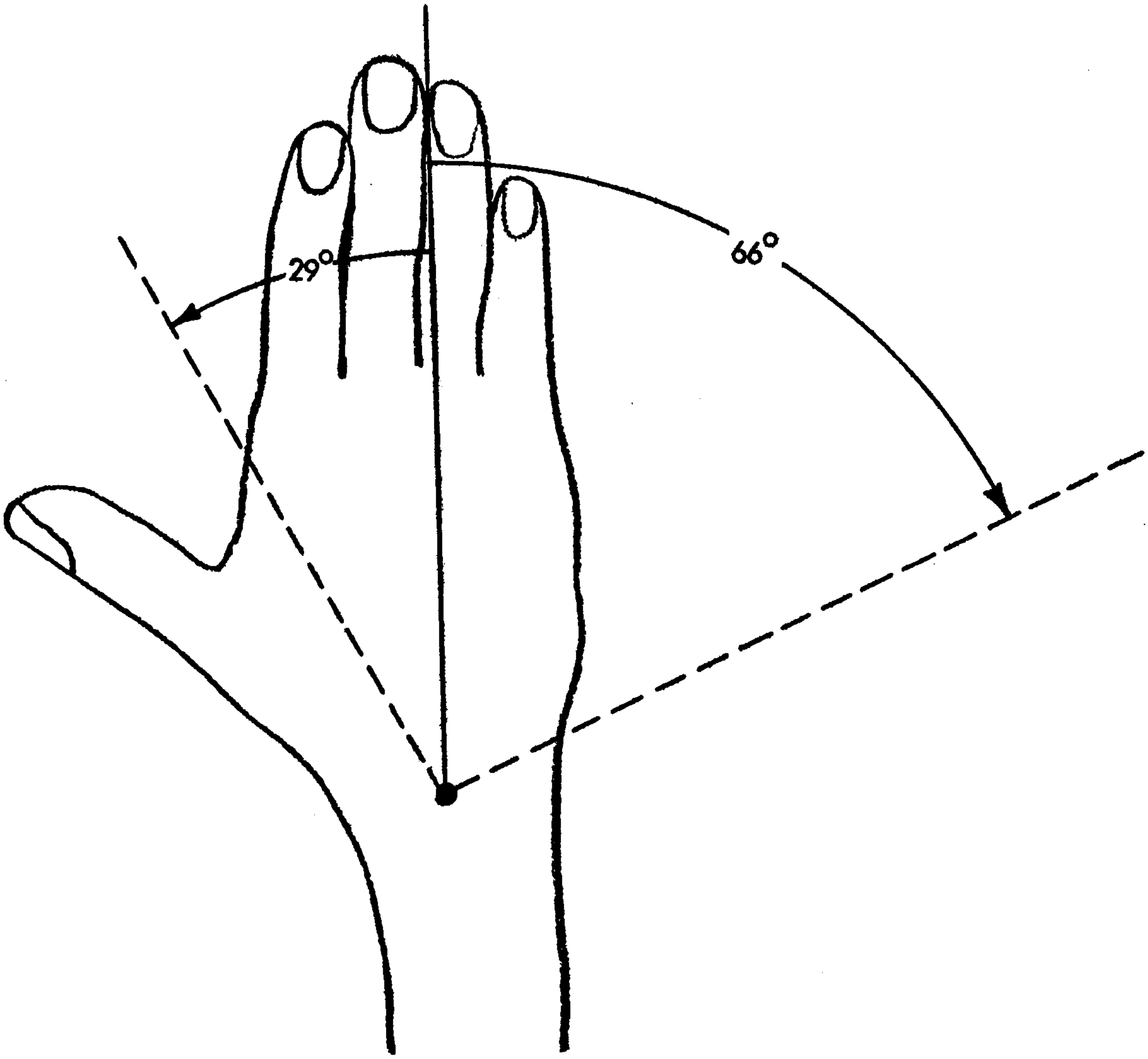

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Figure 53.

Abduction and Adduction of the Hand at the Wrist

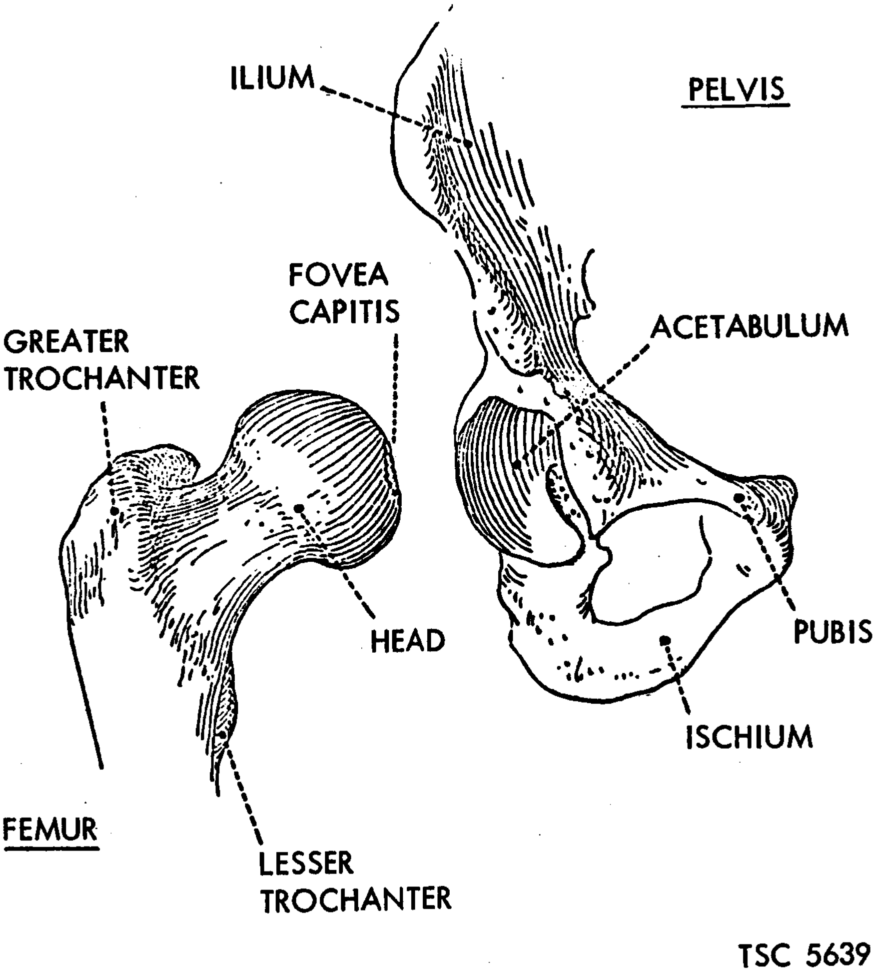

Figure 54. Bones of Hip Joint

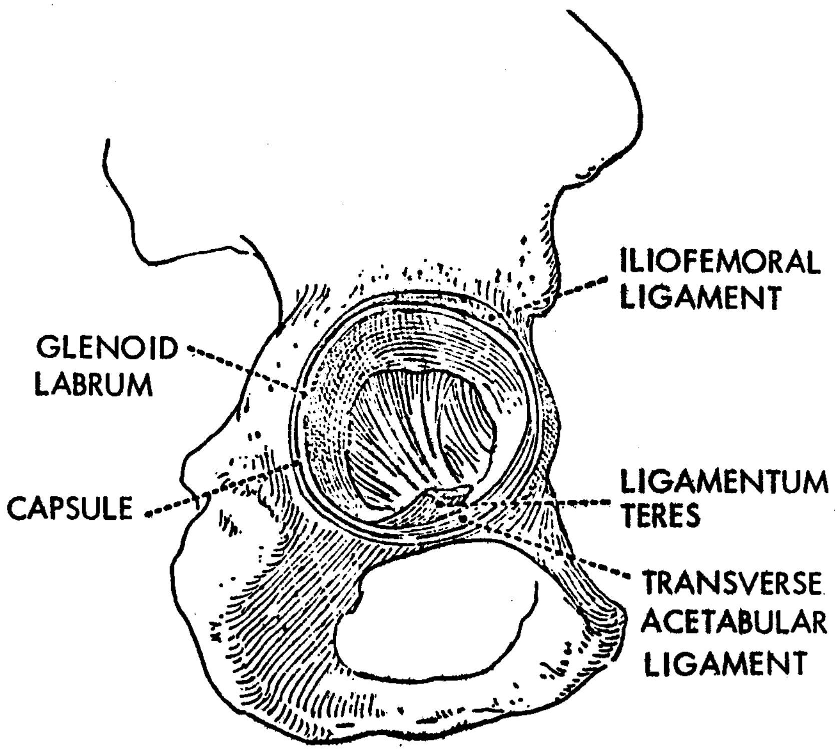

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Figure 55. Acetabulum of Right Hip Joint

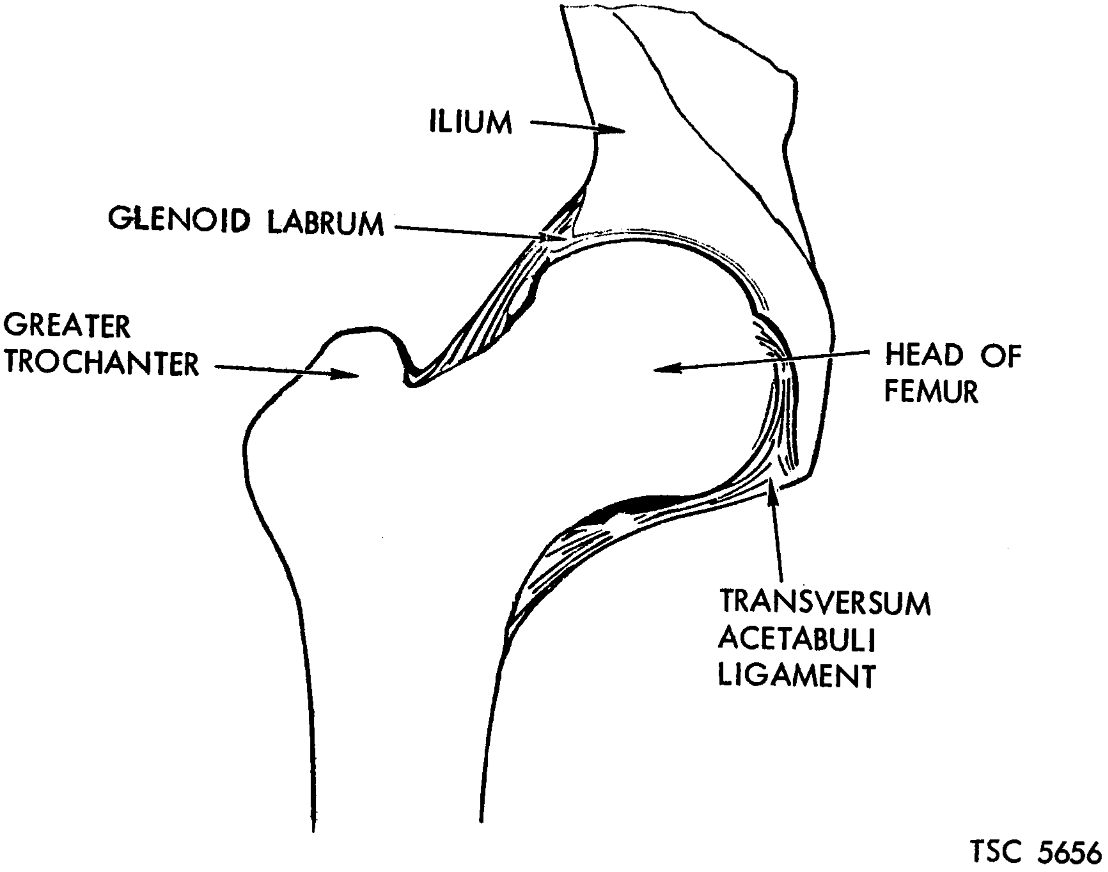

Figure 56.

Ligamental Support of Head of Femur

4.2.9 Bionic Application of the Biomechanisms of Human Motion

Thus far, this section on the biomechanisms of human motion has been concerned largely with the anatomical and kinematic implications of the musculo-skeletal subsystem. Utilizing the material that has been presented, it is now appropriate to consider a bionic application. Since the majority of the material that has been discussed has dealt with the joints of the shoulder-arm complex, let this be the portion of man that will be developed as a machine analog.

Machine analogs of the shoulder-arm complex have been in development for some time. Ever since the production of highly radioactive materials, remote arm- and hand-like devices have been in use. These devices have been grouped under a general category called manipulators. NASA will be making extensive use of manipulators in the hostile environment of space where rotary joints are not satisfactory. Undersea exploration and oil drilling operations have already advanced to the stage where there are rather sophisticated manipulators in use.

In the "Los Angeles Times" of 4 April 1965, there appeared an article by Joe. R. Nevarez on manipulators used in undersea drilling. This article is reproduced on the following pages as a bionic application of the shoulder-arm complex.

Los Angeles Times Outlook
SECTION 1
SUNDAY, APRIL 4, 1965
Business • Finance • Travel

UNDERSEA DRILLING: CLANK OF ROBOT FEET TO KEEP STEP WITH MAN'S NEED

By Joe R. Nevarez
Times Staff Writer

THE IMAGINATION of a Jules Verne, plus space-age techniques will send a variety of creatures to invade the ocean depths in a modern gold rush, the search for offshore oil fields.

And petroleum companies will pour more money into the underwater world as manned submarines — Alvin, the Beaver, the Purisima, the Turtle — and robots — Mobot and Unomo — come into practical use with offshore drilling fleets.

Many millions of dollars will be spent in developing these fantastic "creatures of the deep" to meet the demand for oil, generated in part by the world-wide population and industrial explosion.

Geologists have fanned this fired-up expansion to the sea with indications that the water bottoms of the world offer the best possibilities for new oil discoveries.

Pacific Coast waters are a principal source for experimental craft tests, currently being done off San Diego, Santa Barbara, and Seattle, Wash.

Southern California industrial firms, including area aerospace companies, are spawning a new generation of manned submarines in the world-wide scramble to explore the last storehouse of oil. The submarines will be used in directing robots' work.

Alvin, developed by the Applied Science Divison of Litton Industries of Beverly Hills, is a two-man 13-ton submarine capable of maneuvering to a depth of 6,000 feet. It is 22-feet long with a maximum speed of 6 knots and 10 hours endurance underwater.

Beaver, (Figure 57) developed by the Autonetics Division of North American Aviation Co., Los Angeles, is another two-man submarine. Developed to work 1,000 feet under water, it will have "arms and hands" — four mechanical manipulators to do deep diving work. The arms can be fitted with impact wrenches, stud guns, jet pumps, wire brushes, grinding wheels and cable cutters. Beaver is now being tested at Autonetics' Anaheim plant.

The Turtle, undergoing tests in the underwater missile facility at Lockheed Aircraft Corp.'s Sunnyvale plant, is designed to probe sea depths at 10,000 feet and beyond with manipulating equipment. It is a newer kind of submersible, a "bottom sitter". It resembles two sand dollars or sea biscuits with their flat sides put together. Engineers at the Sunnyvale plant say the Turtle generates a minimum of noise and, by operating in the sub-surface, avoids rough weather.

Two other underwater vehicles, the Aluminaut and the Diving Saucer, are currently being tested off the California coast.

Aluminaut, developed by Reynolds International, Inc., subsidiary of Reynolds Metals Co., was built by the Electric Boat Division of General

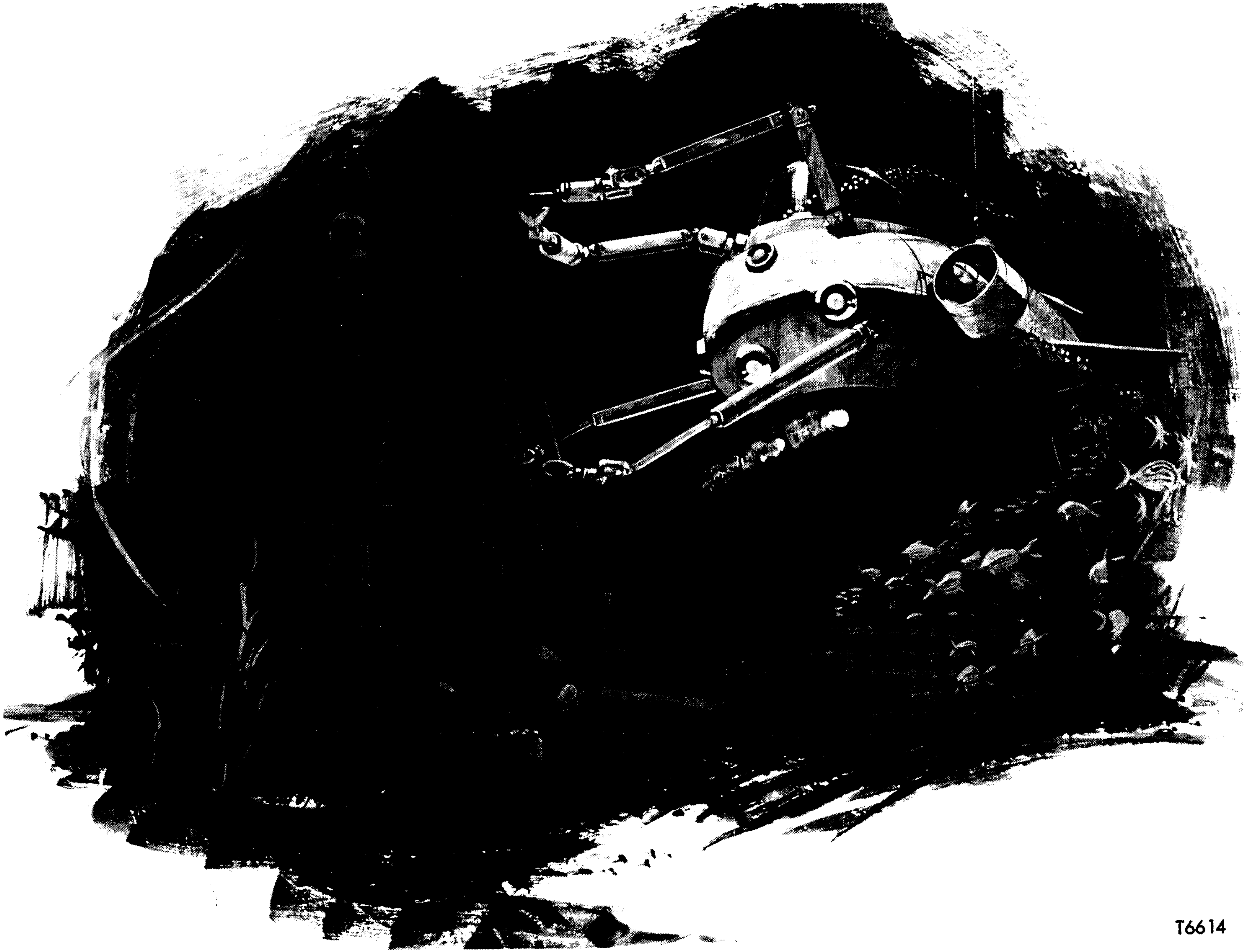

Figure 57. Manipulator developed by Anaheim Autonetics Division of North American Aviation, Inc., is used on The Beaver, which is a two-man submerisble.

Dynamics Corp. at a cost of $3 million. Said to be the world's deepest diving submarine, the Aluminaut is able to probe depths of 15,000 feet. It is 51 feet long, has two hemisperical-shaped heads, sonar system, television and robot hands.

The Diving Saucer, developed by Jacques Yves Cousteau of France, is leased out in the United States by Westinghouse Corp. through its World Wide Charter Facilities Division.

The Diving Saucer has one arm and is capable of diving in up to 1,000 feet of water. It is considered a good surveying tool for underwater pipelines and new oil deposits. Recent tests have been undertaken off La Jolla, San Diego, Santa Barbara and Baja California.

The two-man Diving Saucer weighs about 7,000 pounds and is about 10 feet in diameter and five feet high. It is propelled by two water jets mounted on its sides. It can turn on a dime if one of the jets is reversed and the other kept in its normal position. Its submerged speed is one knot, slightly over one mile an hour. The two crew members, a pilot and an observer, lie in a prone position. A mechanical arm on the front of the saucer enables the crew to perform a variety of functions.

3 Deepstars

The first Deepstar, a three-man version of the D wing saucer, will be completed by mid-year and will be capable of descending to 4,000 feet. Work is also continuing on another three-man Deepstar with a depth capacity of 12,-000 feet.

Preliminary design work is also being done on a third Deepstar for 20,000 foot operations. The Deepstar-1200 will weigh about seven tons and will be able to stay submerged with its three crewmen for 24 hours.

The role of robots is played by Shell Oil Co.'s Mobot and the newer Unomo. Both were developed by Hughes Aircraft Co.'s Nucleonics Division in Fullerton.

Shell's Mobot uses a socket wrench to do its work. It handles flange bolts on underwater drilling equipment and well heads. It also carriers sonar for locating underwater equipment and a TV camera.

Hughes' Unomo has four working arms, two of them with clamps and two for manipulation. It mounts fixed and mobile TV cameras, underwater lights. sonar and propulsion equipment. It has gone to a depth of 840 feet in recent tests in California waters.

Each of its arms contains nine motors and includes a shoulder, elbow, wrist and hand, controlled by TV from a surface ship. It is one of the few devices available for rental at this time.

Rate for an 8-hour shift is $2, 500, with overtime at $315 per hour. For a five-day, 40 hour week, with an operator, the model is $11, 000 and for a month, $39, 600, also with the $315 hour overtime provision.

Human Divers Needed

Because even robots can make errors, human divers are still needed to overcome malfunctions, retrieve dropped equipment and make final inspections as the treasures of the sea are sought.

Ocean Systems, Inc., formed by Union Carbide Corp., General Precision Equipment Corp. and oceanologist Edwin A. Link, plans to handle industrial projects including drilling of underwater oil wells.

H. D. (Danny) Wilson heads up Offshore Divers, Inc., of Santa Barbara and Seattle, division of Ocean Systems, with 40 divers — the largest group in the world, all capable of working at depths up to 400 feet.

When asked about costs, Wilson refused to quote charges, but did say "human divers are cheaper than robots, and, they have brains." He added the firm's goal is to extend working dives to the 600-foot level.

The firm is now testing oil-industry divers at 500 feet for the first time off the Santa Barbara coast with a new five-ton double-sphere vessel named the Purisima. It consists of two five-foot pressure chambers, connected by double hatches holding one man confortably.

In the upper sphere is a backup diver or an oil-company observe. A working diver in the lower sphere can leave through a hatch in the bottom to perform his work. The backup diver can pressurize the chamber, drop through to the bottom sphere, and replace or help the first diver.

5.0 APPLICATION OF BIONIC DEVICES

During the period of performance of this contract, Teledyne Systems Corporation has investigated three of the subsystems of man and has suggested various bionic devices that could be designed utilizing the principles of operation of each biological subsystem. Now it is possible to suggest a bionic system that incorporates all three of these subsystems.

Before describing this bionic system, let us review the subsystems that have been previously studied. The first biological subsystem that was studied was the eye, the second was the nervous subsystem, and the third was the musculo-skeletal subsystem. Utilizing the Man-Machine Methodology to develop the human analog of the visual sensor, the principles of operation of the eye were developed and recorded on the appropriate information sheets. Thus, the basic approach to the design of visual sensors has been formulated, and a photoreceptor-like element with its associated optics can be conceived.

The second subsystem studied included a survey of the operation of the fundamental unit of the nervous subsystem and the development of a neuron-like element. This non-numeric data handling element can be used to form the basic building block of a system that can store input data, correlate new data with data already in the memory, and sense and store data pertaining to the internal state of the system. The system will be able to learn by experience and, therefore, is adaptive. It can be conditioned to yield a specific output after searching for and finding desired information. Thus, a non-numeric system can be programmed to seek a desired goal.

Research into the articulations of the body has yielded some of the biological techniques used to connect moving limbs. These techniques can be highly useful in designing mechanical devices that must operate in hostile environments. Light weight, low power loss, biological type joints can be designed to provide the mechanical linkages between moving parts in a machine analog.

One possible bionic application of the subsystems that have been studied is a goal seeking visual sensor. The machine analog of the eye can be utilized as the sensor portion, and the non-numeric element can be used as the fundamental building block of a goal oriented data handling system. Mechanical connections in the goal seeking system that transmit movement can be designed by considering biological articulations.

This system would be capable of relaying back, from a selected remote site, information quite unlike that obtained from a television system. Data received would enable scientists to answer specific questions about the characteristics of the object that is found at the remote site. Visual characteristics can be defined by stating the set membership or lack of membership for a specific trait. For example, an object could have set membership in those objects that are spherical, or square, or irregular in shape. By combining information about a number of sets, membership in more complex groups can be derived, and a statement such as, "That object is a member of the group called houses", can be made.

Specific analysis can be accomplished, and detailed information on any facet of the image, to the level desired, may be extracted from the visual goal seeking system for those sets of characteristics that have been "taught" to the system. One possible application of the visual goal seeking system would be to examine the dust on the surface of the moon. After the system is established on the moon, the visual sensor can be directed to examine the dust, and information can be requested from the earth on the texture, coarseness, or fineness of the dust, or on any other dust property that is of interest as long as the system is operating within the scope of its previous training.

By only considering set membership, the amount of data that must be transmitted can be greatly reduced. Most present day real time high quality video transmissions require a bandwidth of about six megacycles and thus consume a considerable amount of power. By compressing the data that must be transmitted, the bandwidth may be reduced, and a resultant savings in power can be realized. The difference in the bandwidth required for a television system and a visual goal-seeking system should be considerable. A goal-seeking system would only need to transmit the number of the memory plane in order to identify the set that describes a particular trait. From the earth, a query signal could be sent to a system that, for example, is on the surface of the moon. An initial question may ask for the number of the memory plane that describes the slope of the lunar surface in the area surrounding the remote system. Next, the texture of the soil could be requested, and so on, until all of the desired questions have been answered. The exchange of only a few numbers is sufficient to detail almost any visual trait.

Perhaps the reason for the introduction of numbers into a system that is based on non-numeric data handling techniques should be clarified. The numbers are only needed because it is desired to transmit information from a remote site. For example, consider a weather satellite containing a goal-seeking system. While the system was on the earth, training could be conducted so that major weather conditions such as cyclones, tornadoes, and hurricanes could be recognized. In addition, the various types of cyclones, tornadoes, hurricanes, etc. could be taught to the goal seeking system. Then when the satellite is circling the earth, the goal seeking system could be directed to report on the types of major weather conditions that it is able to locate. The report could simply be the number of the activated information planes. On earth, the number could be fed into a similar goal seeking system and the appropriate information plane would be excited.

An application of the goal oriented system can be made to the situation of an astronaut, who must visually monitor a large number of dials and gauges. A considerable portion of the information obtained by observing a bank of dials and gauges is not important to the astronaut. Generally, a display indicating that a system is operating normally does not require the attention of a human observer. To free the astronaut from this task, a goal oriented system may be used to monitor these dials and gauges. In this application, the goal of the system is to locate those dials and gauges that indicate undesired conditions in equipments. The goal oriented system could be trained to produce an output that would inform the astronaut of the equipment that was malfunctioning. Even further, the goal oriented system could suggest the needed corrective action. Preprogrammed directions could be stored in the non-numeric data handling system so that it would be able to make certain corrective actions without human intervention. Thus, the goal oriented system would relieve the astronaut of a considerable burden and only claim his attention when the monitoring instruments indicate that an unwanted condition exists for a particular equipment.

6.0 CONCLUSIONS

In reviewing this final report and attempting to assess the value of the research effort which has been expended, it can be concluded that the first attempt to apply the principles of the Man-Machine Methodology has been highly fruitful. Considering that this contract represents the first effort in utilizing the Methodology, the resultant final report is rather complete, and interestingly the three separately researched areas of vision, nervous subsystem operation, and musculo-skeletal subsystem operation, have merged smoothly into a single coherent report.

Most of the credit for the unity of this report is due to the organization that has been provided by the Man-Machine Methodology. In the writing of the contract for "Research in Advanced Concepts in Biotechnology, Human Analogs, and Bionics", the cognizant NASA representatives have chosen to draw the basic objectives of this research effort from the Man-Machine Methodology. Thus, Teledyne was contractually directed to study an energy input subsystem of man, a distribution and control subsystem, and an energy output subsystem using the principles of the Methodology. Even the fundamental statement that man is composed of energy input subsystems, distribution and control subsystems, and energy output subsystems is a rigorous part of the Methodology, and by NASA's suggestion to study one of each of these subsystems, a unified research effort has been produced.

Even though each of the subsystems, which have been selected for study, have not been chosen with deliberate foresight toward eventual merger, the final report that has been constructed of three separate pieces has become a completely connected whole. An example of the unity that has been achieved can be found in the section entitled "Application of Bionic Devices". This section was written to indicate how the three separately developed human analogs of the eye, the nervous subsystem, and the musculo-skeletal subsystem can be integrated in the design of bionics systems. The ease of design of bionic systems from these three human analogs is apparent in that section. Indeed, if this entire research effort has established one new principle, it is the usefulness of the human analog.

Research into the operation of the visual sensor has developed the human analog of the eye. The human analog has been constructed by filling out a group of tabular forms for each Methodological aspect. This method of developing the haman analog has proved to have a number of desirable features. Tabular format has allowed a non-linear system, such as the eye, to be described. Lack of applicable differential equations that could be used to construct a human analog has not been an obstacle. Every piece of data that was produced was found to have a specific place on the Information Sheets.

Comparing the human analog that this report has produced to previous efforts at describing the operation of the eye, the merits of the present approach may be realized. Prior physiological investigation approached the eye by dissecting it into arbitrary anatomical parts and then analyzing the function of each of these pieces. Table 5 is a listing of 66 of the components of the human eye. Though this listing is quite lengthy, it is not complete, because many ocular anatomists will desire to add a few more components. Even physiologists will not be satisfied with this list.

Cornea

1. Basal cells
2. Polyhedral cells
3. Epithelial cells
4. Endothelial cells
5. Corneal corpuscles (fixed cells)
6. Leucocytes (wandering cells)
7. Lymph cells
8. Nerve cells (neurons)
9. Vascular loops (blood vessels)
10. Bowman's membrane
11. Descemet's membrane
12. Elastic fibers
13. Inelastic fibers (collagenous fibers)

Iris

14. Epithelial cells
15. Endothelial cells
16. Pigment cells
17. Vascular loops
18. Inelastic fibers
19. Elastic fibers
20. Dilator muscle
21. Sphincter muscle

Lens

22. Epithelial cells
23. Lens fibers
24. Cement substance
25. Suspensory fibers

Ciliary Muscle

26. Muscle fibers
27. Elastic tissue
28. Nerve cells

Ciliary Body

29. Pigment cells
30. Epithelial cells
31. Hyaloid cells
32. Processes
33. Vascular loops
34. Connective tissue

Retina

35. Pigment epithelium
36. Rod cells
37. Cone cells
38. Centripetal cells
39. Ganglion cells
40. Horizontal cells
41. Amacrine cells
42. Centrifugal cells
43. Centrifugal fibers
44. Muller fibers

45. Optic Nerve

46. Aqueous Humor

47. Vitreous Body

Sclera

48. Inelastic fibers (collagenous fibers)
49. Elastic fibers
50. Fixed cells
51. Pigment cells
52. Nerve cells
53. Vascular loops

54. Conjunctiva
55. Levator muscle

Muscles

56. Superior rectus
57. Inferior rectus
58. Lateral rectus
59. Medial rectus
60. Superior oblique
61. Inferior oblique

Choroid

62. Vascular loops
63. Pigment cells
64. Hyaloid cells
65. Elastic fibers
66. Inelastic fibers (collagenous fibers)

COMPONENTS OF THE HUMAN EYE

Table 5

They may choose to delete components. Neither of these researchers will give consideration to how the function of any component contributes to the operation of the entire eye. An example of this concern with detail is the concentration on each of the types of cells within the cornea while ignoring their contribution to the visual process. Table 5 lists thirteen cornea components that are separately analyzed in ocular anatomy. As this table indicates, the eye has been divided into dozens of cellular components by the anatomists, and as a result, investigators that have studied functional relationships of a few of these parts have not produced basic insights into the visual process.

A comprehensive study of most of these components is not warrented. Knowledge of the processes conducted within a few components could, however, give insight into a considerable segment of the visual mechanism. This may be illustrated by examining the basic visual functions of a number of parts of the eye. Examples of visual functions are indicated in the following list: cornea-frequency and intensity filtering and refraction of light; lens - refraction of light; and iris - control of amount of light entering eye. There are many other parts of the eye that have visual functions that are well known, but there are components that perform a large and complex portion of the visual process and are not presently well understood. These are the components that deserve study.

The Man-Machine Methodology does not allow the investigator to become entangled in details. A few of the 66 components of the eye could not be randomly selected and studied in minute detail, so that the investigator is able to lose sight of gaining an understanding of the fundamental operation of the eye.

In the research that has been conducted, attention was directed toward keeping extraneous details out while striving to utilize information that would illuminate the visual process. The entire Subsystem investigation was carried out in a framework that oriented data toward a clearer understanding of the human eye. Each intersection of the Subsystem Matrix considered provided a description of another facet of the operation of the entire eye. For all of the intersections discussed, information was directed toward explaining the overall subsystem and not in developing relationships between the various facets. Anatomical data has been primarily grouped under the heading Configuration Information and has thus been separated in each file.

One of the guiding principles that was utilized by the Function Influencing Factor was to trace the information signal. Each of the aspects considered under Function presented a description of this signal during a specific phase. A basic question was answered when a description of how the eye detects the information signal was given. As this signal was traced, a clear idea of the form of the information envelope was obtained. For example, the information signal was in the form of transverse ion flow within the neurons of the retina. The composition of the signal as well as the energy conversions undergone were described. Concentration on tracing the information signal has produced a human analog that has described the basic processes of the eye. The Man-Machine Methodology has suggested that a guide to all scientific investigation concerned with probing functional operation is to trace the flow of the information signal.

If scientific researchers would utilize the Man-Machine Methodology, the important relationships between collected data would become apparent.

The Methodological framework represents an excellent structure to store all pertinent information. Prior to applying the Methodology, it is necessary for the scientific researcher to gain a general familiarity with the subject. This has been illustrated in this contract by the efforts that have been made in the study of the physiology and anatomy of the three subsystems, which have been examined.

The Methodological approach has led to the disclosure of areas in which basic research is needed. In the investigation of the visual Functional Aspect of Detect (File No. 4-79-01), it was found that the literature did not contain an explanation for this function. Thus, one area in which research would be profitable is to study how a structure, such as a rod or cone of the eye, is able to detect frequencies within the visible radiation spectrum. This research could produce results that would apply to the detection of the entire electromagnetic spectrum.

In order to explain how the eye detected and absorbed visible radiation, a hypothesis was proposed in File No. 4-79-01. This hypothesis was based on the phenomenon of resonance. It was assumed that there were resonant structures within the eye that responded to the frequencies of visible radiation. Physiological evidence suggested that these structures were located in the rods and cones. When electromagnetic radiation in the visible spectrum impinged upon the photoreceptors, the latent ability of these structures was utilized and resonance occurred.

The initiation of resonance was considered to constitute the detection function while the actual dislocation of particles was described under the aspect of quantize (File No. 4-80-01). Quantization was hypothesized to commence after the completion of detection. When energy absorption by the resonating structures reached a specific level, electrons were freed from their bonds and moved from the photoreceptor surface into the receptor proper. The energy of the electrons was in proportion to the activity of the visible radiation that was absorbed by the resonant structure.

With the hypothesis above in mind, the investigation of the photoreceptors was continued, but at a more detailed level. A description of the previously hypothesized resonant structures within the photoreceptors was found in the literature and is given in Section 2.2.1. These structures are called π-orbitals and are constructed by the excess electrons that remain after covalent bonds have been formed between the two molecules that compose rhodopsin.

The reported existence of these structures helps to substantiate the resonance hypothesis. H.J.A. Dartnall suggests an explanation of how the resonance process takes place in his book The Visual Pigments, page 133. Dartnall explains that the oscillation of impinging radiation causes the structures with the latent ability to resonate to move back and forth along the conjugated chain, congregating alternately at each end. Only light that is of a frequency that can resonate with the rhythmically oscillating π-orbitals will be strongly absorbed.

Development of the resonance hypothesis, that has been described above, has applications that are much wider than only explaining how the photoreceptors detect visible radiation. The entire electromagnetic frequency range is encompassed by this hypothesis because all energies in this spectrum are absorbed in a similar manner. Basic research that would establish or modify this hypothesis could produce a new fundamental physical law.

The non-numeric element that has been developed in this report is a component that can be well utilized as the building block for advanced data handling systems. The entire development of this element has been closely associated with investigations and observations of the biological neuron in order to insure that the component which was derived would take the fullest possible advantage of the nearly perfect element in the human nervous system. Thus, the non-numeric element is an excellent machine analog of the living neuron.

Many of the essential features of the biological neuron have been incorporated into the non-numeric element. A threshold has been included so that any input to a non-numeric element must exceed a specific value before stimulation occurs. The threshold value can be achieved by only one input, or a number of subliminal inputs can cumulatively act to produce stimulation. Every non-numeric element has gain, so that a signal may be propaged without attenuation as occurs over the length of an axon. There is also an output saturation value for each element.

The non-numeric element was utilized as the basic component in the development of a non-numerical data handling system. This system has the ability to store inputs so that new stimuli can be compared to those in the memory. For digital computers, the task of comparison of complex inputs with previous stored information is a very lengthy and inefficiently conducted effort, while correlation is a straightforward process for a non-numeric system.

The non-numeric data handling element has been utilized as the building block of a correlator in this report. A non-numeric data handling system has been described that incorporates a neuron-like element as the recurring fundamental unit. The capabilities of this data handling system are the following:

1. To accept and store all input data presented to the system sensors.
2. To correlate new data with data already in the memory.
3. To more readily correlate new data with previously stored data if a large degree of similarity can be found in the memory.
4. To treat unfamiliar data cautiously, that is, little or no correlation until sufficient exposure permits the censor to lower the acceptable correlation level.
5. To sense and store patterns pertaining to the internal state of the system.
6. To produce output patterns as a consequence of both external and internal inputs.
7. To possess a mode wherein new patterns can be formed by reprocessing data already contained in the memory.

Thus, it is possible to conceive a system that learns by experience. At any given time, the machine would respond on the basis of all its previously sensed data plus those patterns formed in the second mode of operation. These special mode patterns represent combinations of data that the machine has never experienced but are likely hypotheses based upon separate observations and low contradiction.

The survey of the biomechanisms of human motion that has been conducted makes available to the mechanical designer the basic methods of articulation used in the human body. Utilization of this information can result in machines that are operable successfully in an environment which would seriously affect the lubricant of rotary joints. Beside application to space vehicles, biological-like joints can be utilized for underwater equipments; in fact, ground based equipments that presently have problems because of the escape of lubricant or the entry of foreign particles from an external environment can be redesigned to incorporate this new concept in airtight seals.

Human analogs have been developed in the terminology of the Man-Machine Methodology and thus can be directly applied to the design of machine extenders. Useful machine extenders can be derived from the human analog in a much more straightforward fashion than from a physiological explanation of the operation of a particular biological system. Since the human analog has been organized according to the influencing factors of the Methodology, design information may be easily located under the appropriate factor of environment, function, configuration or material.

Deriving machine extenders from a human analog has the advantage that there is no technical language barrier to hamper the retrieval of information from the Methodological forms. Terminology used in developing the human analog is common to all fields of science, and, thus, a physiologist, who may gather information for the Methodological forms, can easily be understood by an engineer, who may be designing a machine extender. After the designer of machine extenders has become familiar with the applicable data contained in the human analog, he can directly apply this information in the implementation of the device.

By using the human analog, design criteria for machine extenders may be developed that are considerably more sophisticated than presently available. Today there are machine extenders that are based on the most obvious principles of operation of the visual sensor. Enormous optical telescopes have been constructed that simply act as enlarged retinal surfaces in gathering light. For viewing small objects, microscopes have been constructed with components that magnify the image as is the function of the crystalline lens of the eye.

A number of the statements made in the preceding paragraphs may be clarified by tracing through a design example. Consider the design of a device that would enable the eye to operate in an environment of much lower light intensity than the unaided visual sensor. The initial step before beginning to design should be to review the information contained in the file on the visual functional aspect of qualify (File No. 4-80-01). This file contains a discussion of how the eye attenuates the intensity as a function of frequency.

At the Subsystem Level, the aspect of qualify dealt with the entire eye and did not discuss how the individual components attenuated the intensity. Each of the components that filter light should be individually investigated in order to establish how much the entering light is attenuated as it passes through each part of the eye. Such a study will reveal those frequencies that would be most desirable to utilize for optimum performance of the rods under low light level conditions. Now a machine extender could be designed that modifies the light before it enters the eye. The device would transmit the information signal to the visual sensor on the selected frequencies.

After an understanding of the human analog has been accomplished, machines can be designed that work on the same principles as those used by the biological subsystem. Such machines would have advantages over presently available devices. These new machines could operate at low frequencies after detecting the information signal as is the case in the eye. Rather accurate spacial relationships could be transmitted with building blocks that are similar to the neurons in the retina.

Research into human analogs has proved fruitful in many ways. As the first detailed applications of the Man-Machine Methodology at the Subsystem Level, this report serves as a model for future research. The human analog has located some areas that could profit greatly by physiological investigation. It was found that studies of organic subsystems could produce more insight into biological processes by following the format of the Man-Machine Methodology. Many scientific researchers in diverse fields of study can profit by a close examination of the human analogs that have been produced by applying the Man-Machine Methodology.

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